OCTOBER, 1958

# JOURNAL OF THE IRON AND STEEL INSTITUTE

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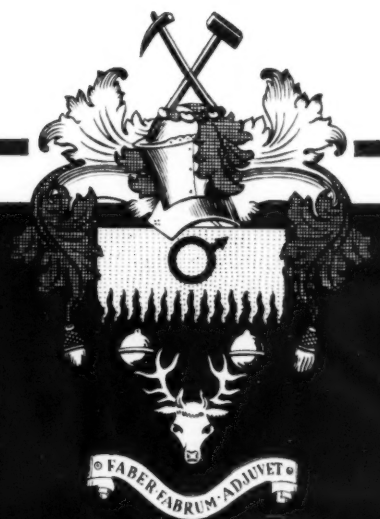


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# where and when they're wanted

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GUNNING COMPOUNDS
STEEL MOULDER'S COMPOSITION
HIGH FREQUENCY FURNACE LININGS
SILICEOUS LADLE JOINTING

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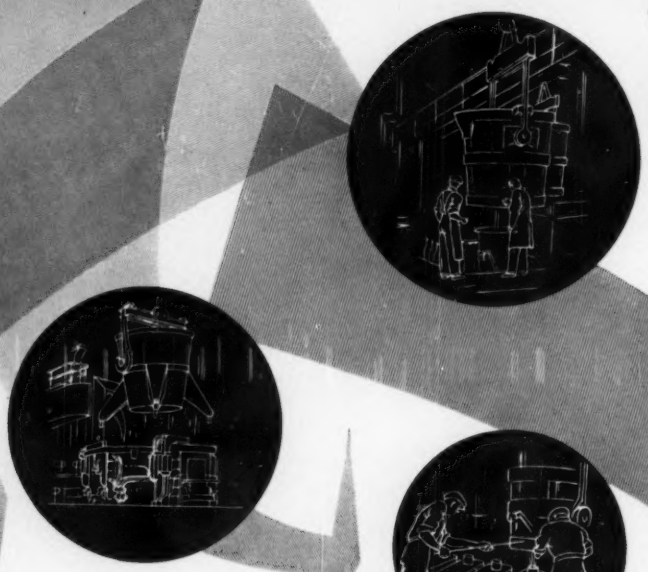

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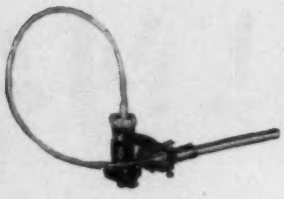

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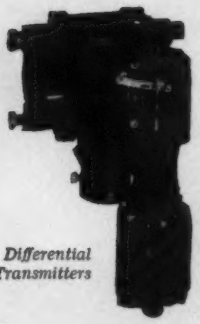

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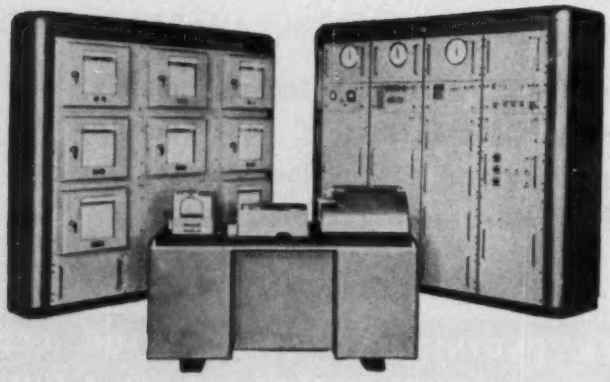

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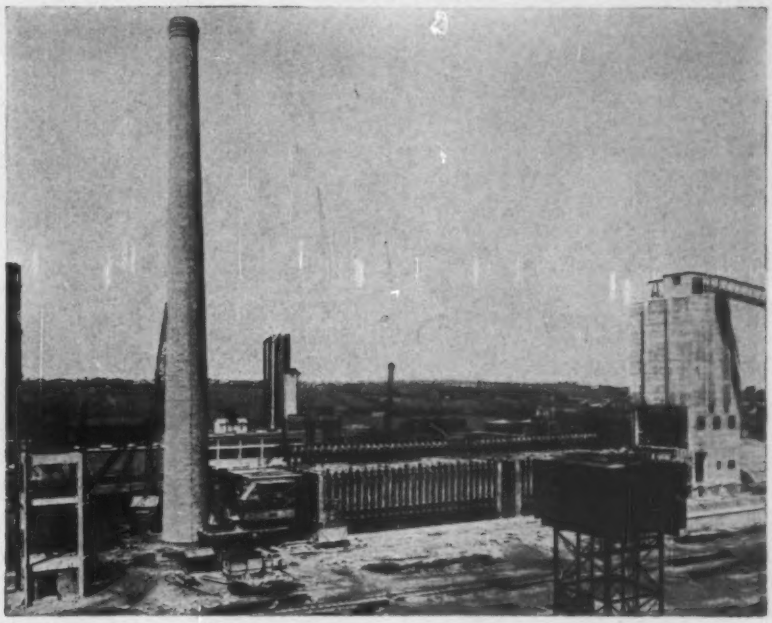

Part of the Durham Divisional Coal Board's scheme for a combined mine, washery and coke producing unit, the Murton Coking Plant, with its very advanced system of centralised instrumentation to assist operational control, is nearing completion.

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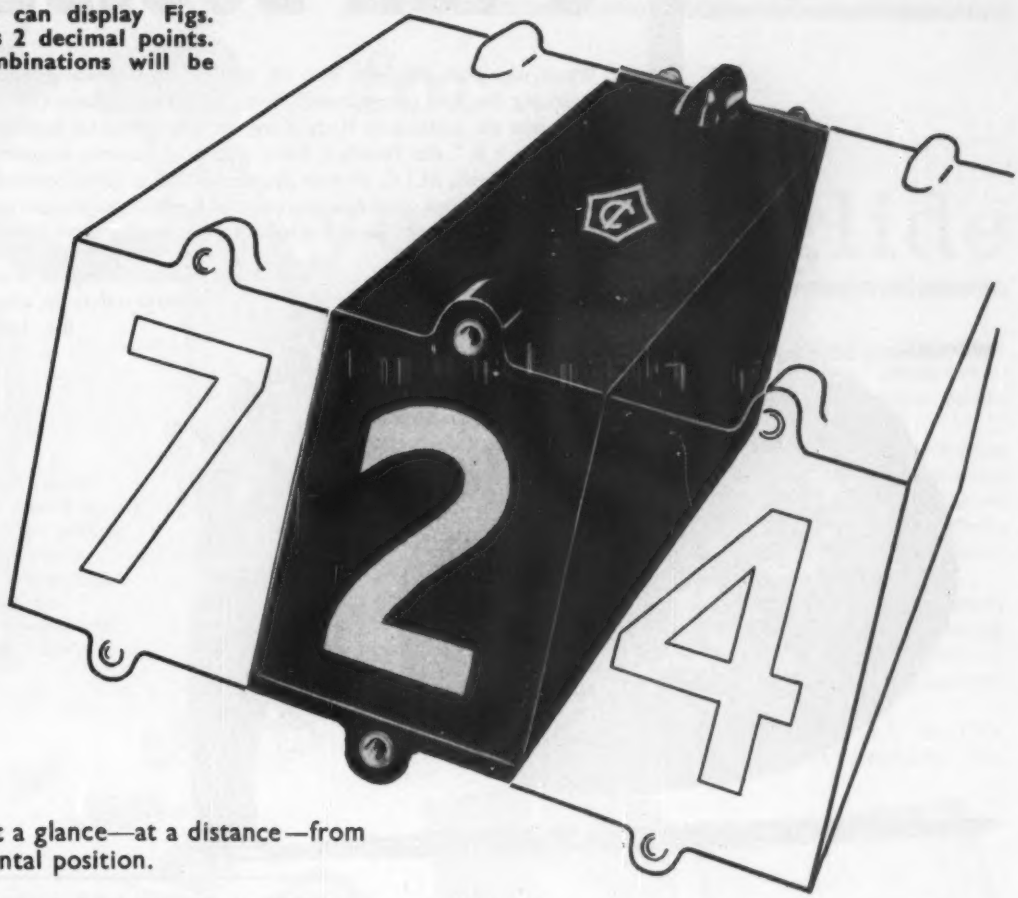


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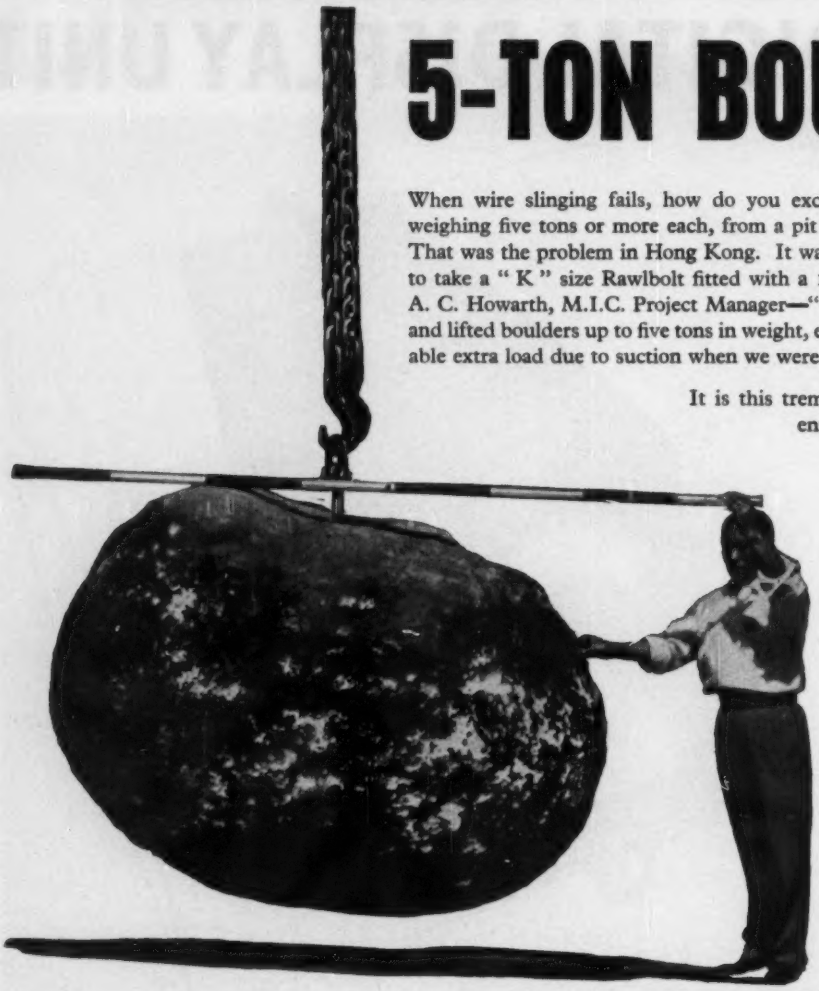

*We are indebted to Messrs. George Wimpey & Co. Ltd., the Building and Civil Engineering Contractors, for the above information. The photograph was kindly provided by Mr. Howarth from the North Point Generating Station, Hong Kong.*

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(2)

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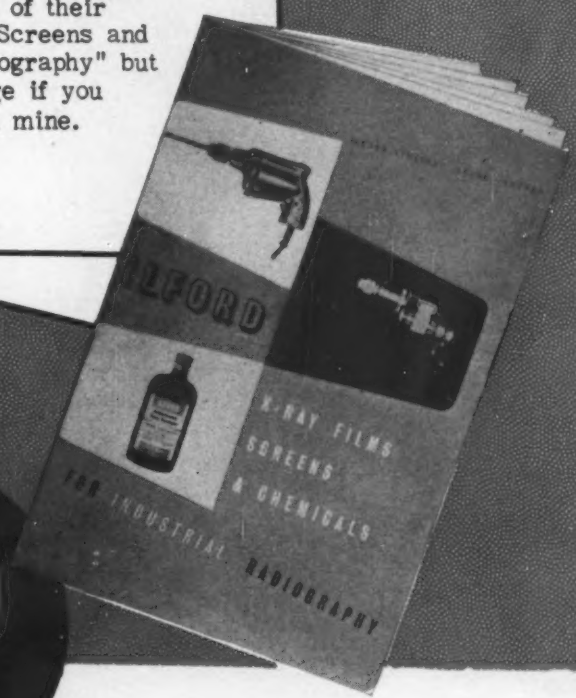


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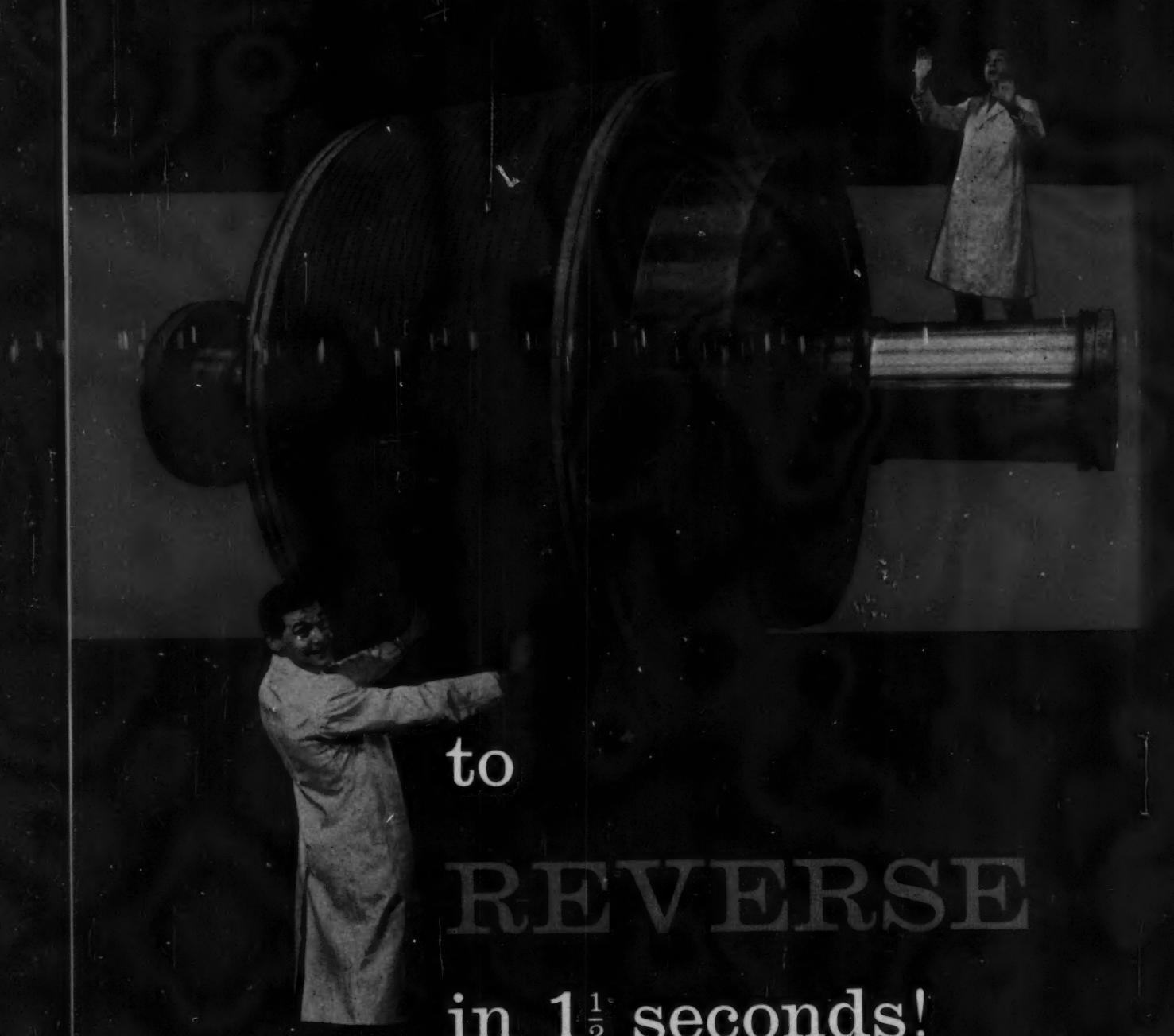

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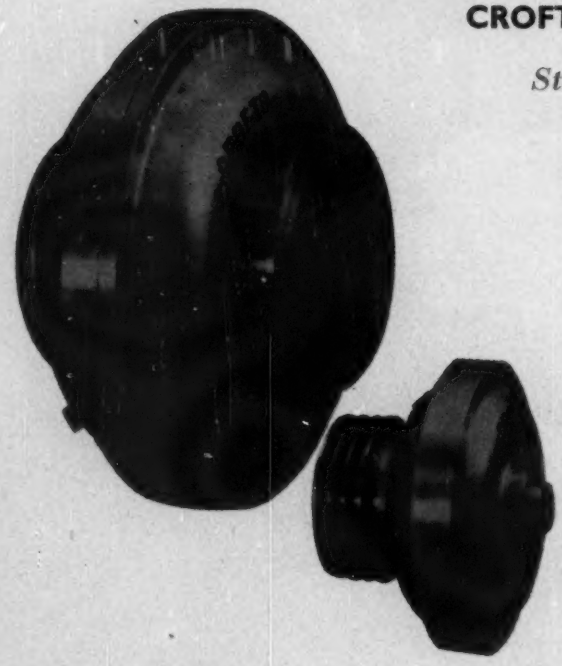

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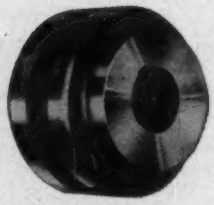

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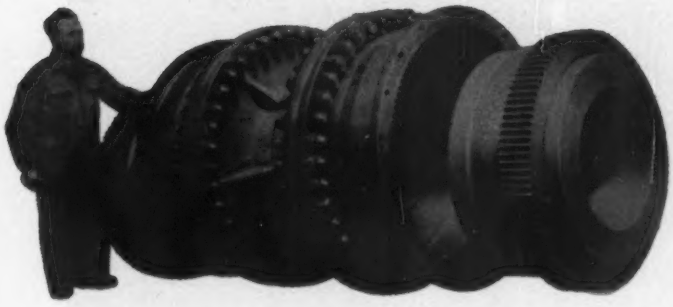

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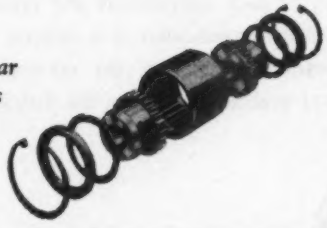

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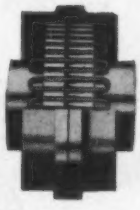

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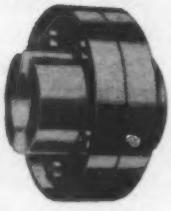

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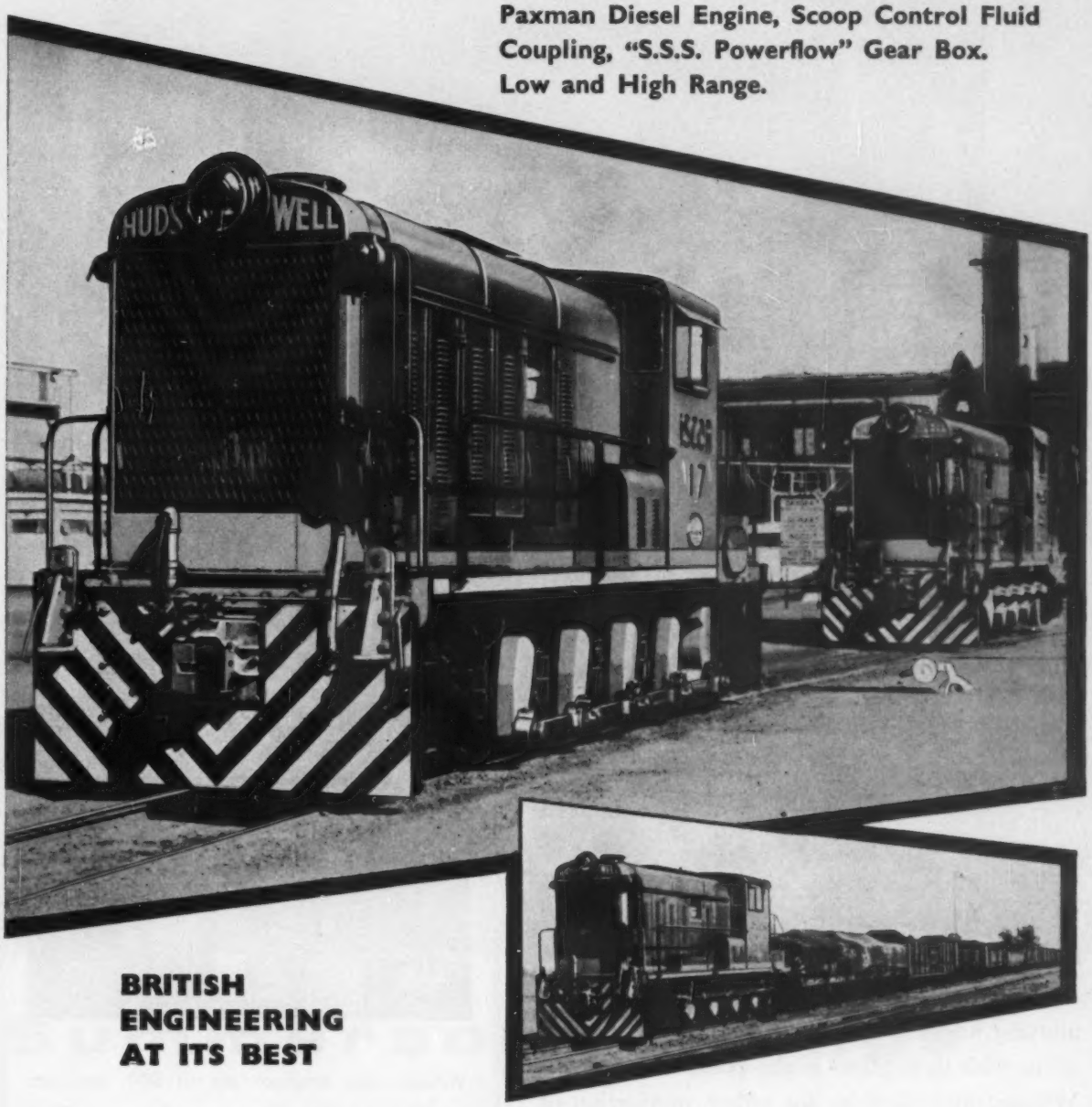


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OA/1452

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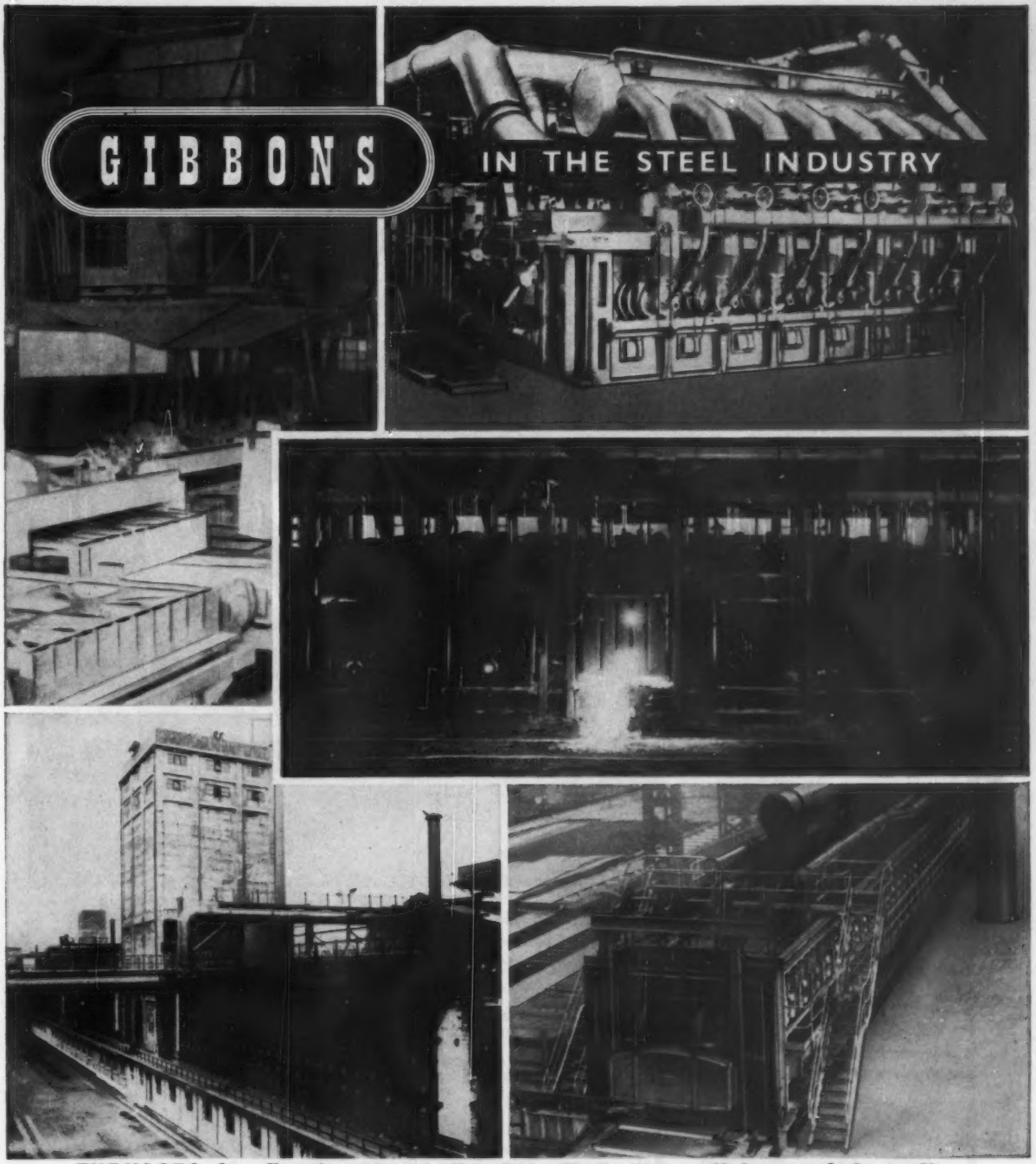


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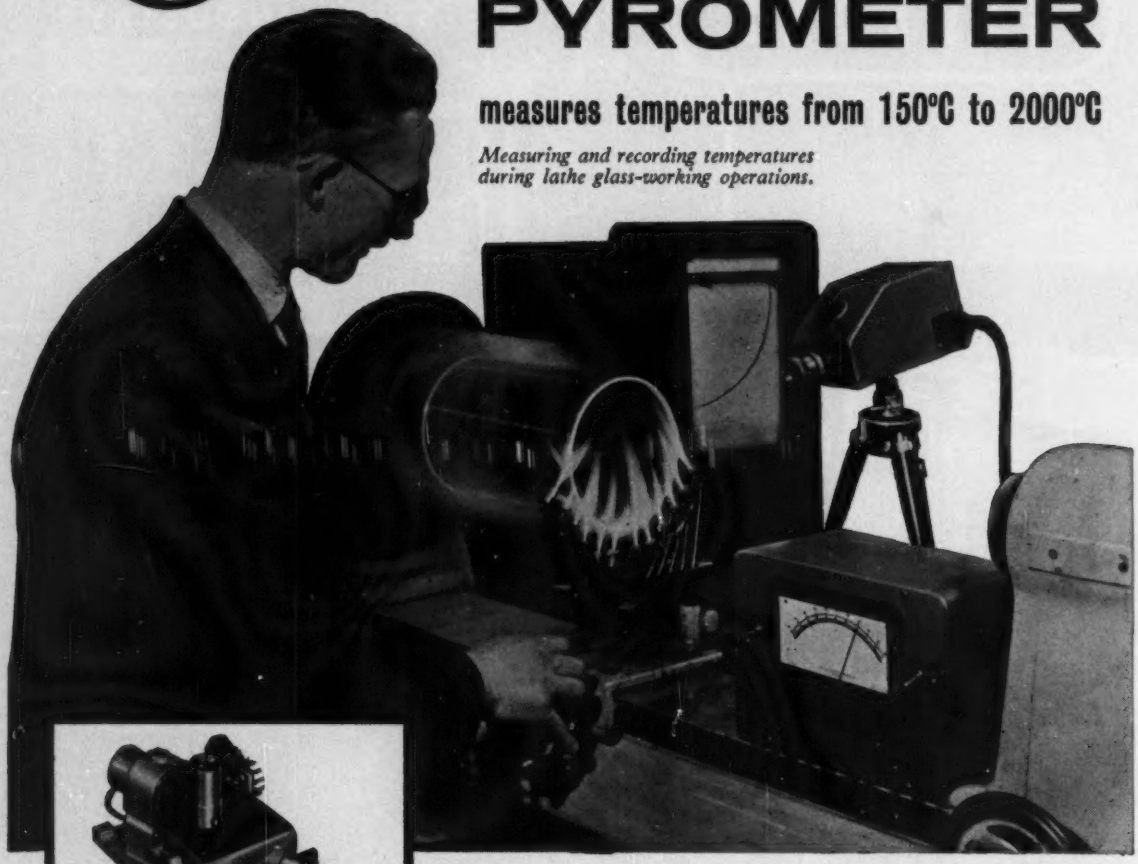
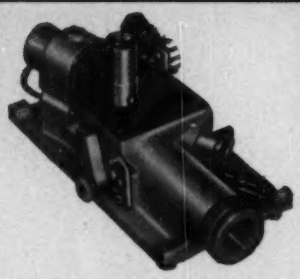
# INFRA-RED RADIATION

# PYROMETER

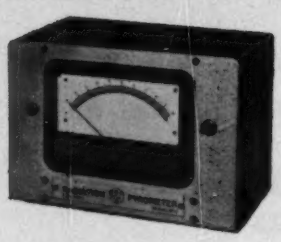
## measures temperatures from 150°C to 2000°C

*Measuring and recording temperatures during lathe glass-working operations.*





*Viewing head of BTH Infra-red pyrometer, cover removed.*



*Control and indication unit.*

This versatile instrument provides a ready means of ascertaining the temperature of stationary or moving objects by measuring the intensity of infra-red radiation emitted from a surface, the viewing area of which can be as little as 0.4 in. diameter.

Light in weight due to the use of transistor amplifier circuits, and easy to set up and operate, the pyrometer lends itself to a wide range of industrial applications, including production-line testing.

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**Steelmaking**—Temperature measurement of strips, bars, ingots.
**Rolling Mills**—Checking roll temperatures.
**Motor Industry**—Checking temperatures of brake discs or shoes.
**Railway Engineering**—Temperature checks on wheels, brakes, axle-boxes.
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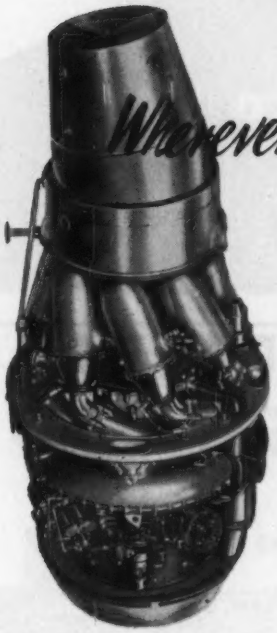

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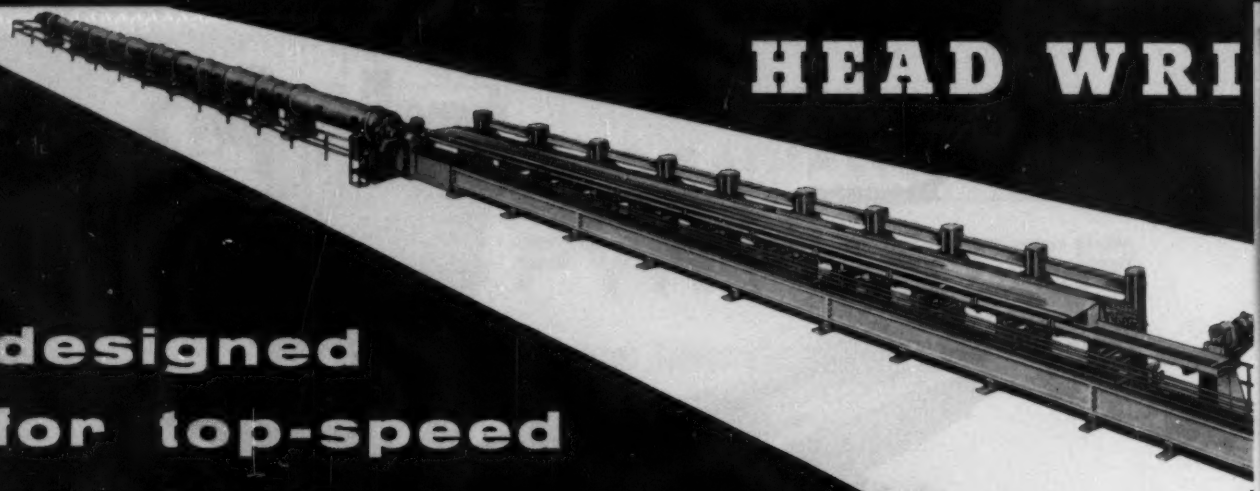

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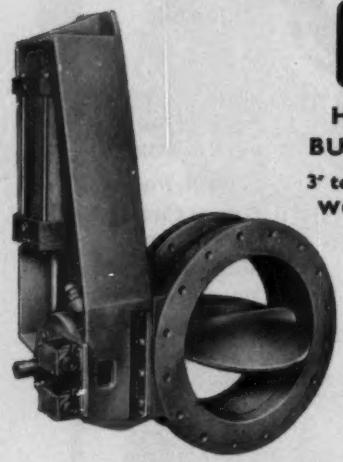

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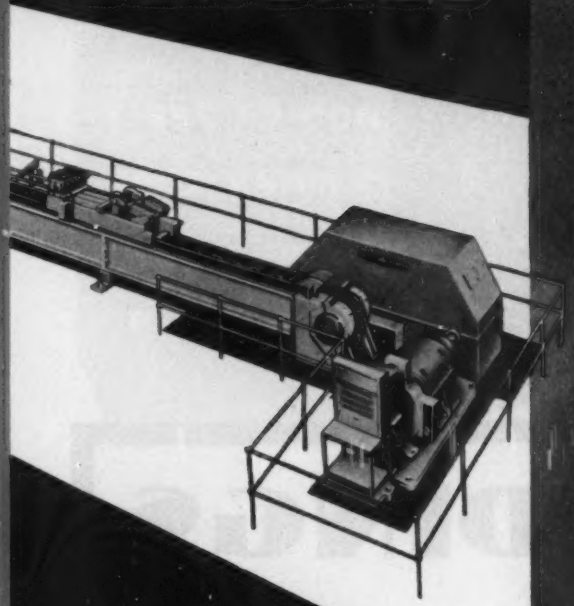

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*The photographs show recently completed sidings on the Phurnacite Plant, Aberaman, S. Wales, reproduced by kind permission of the National Coal Board.*

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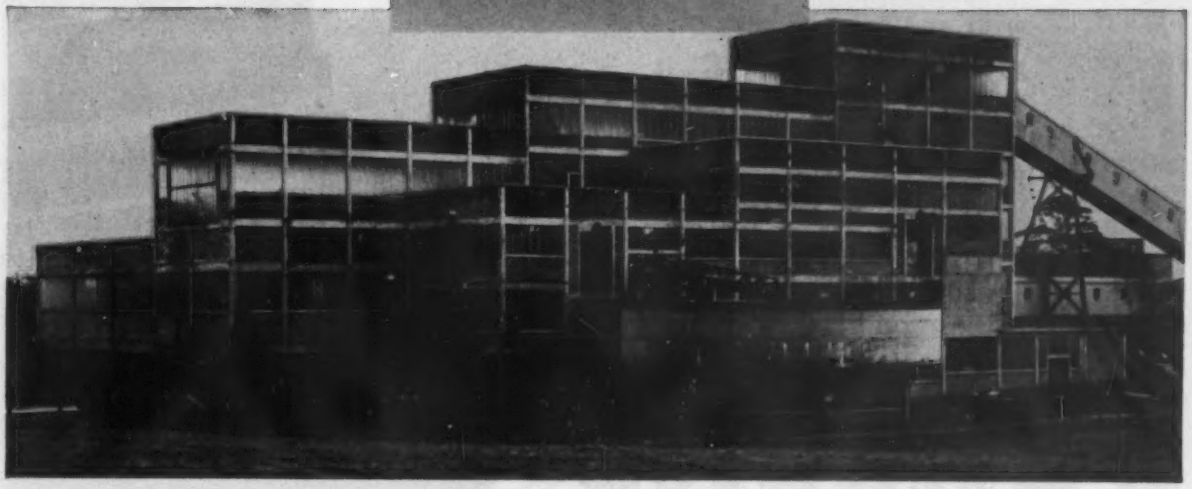

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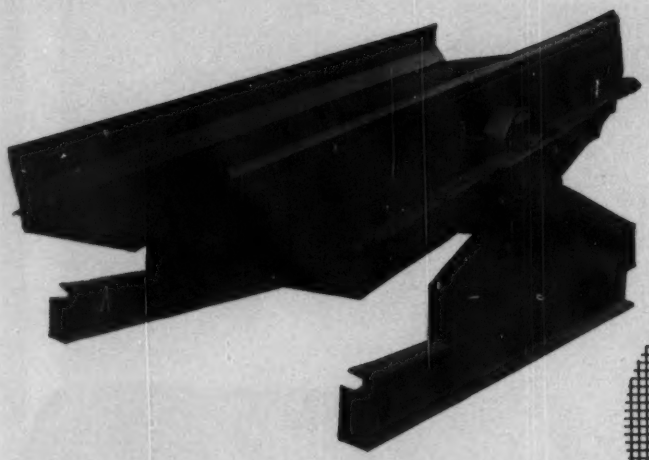

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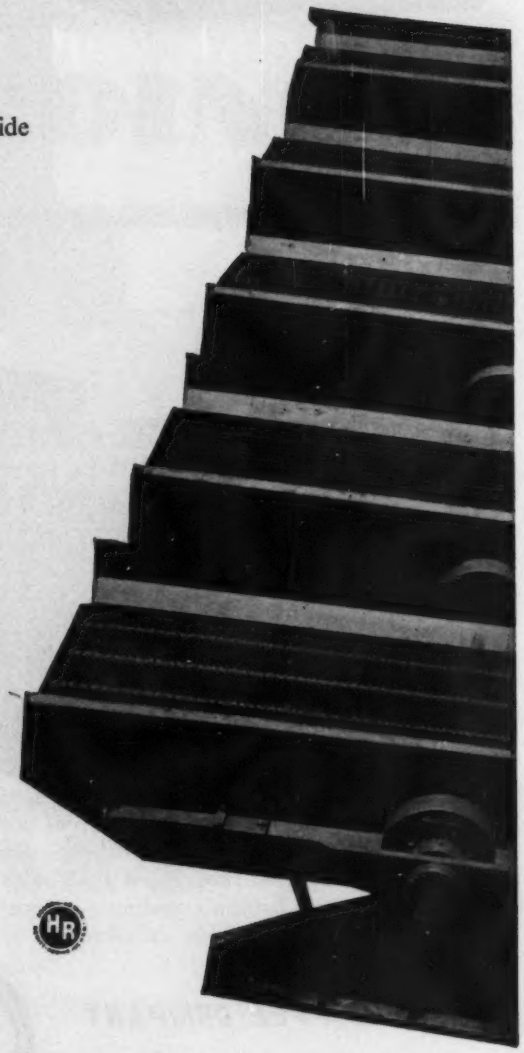

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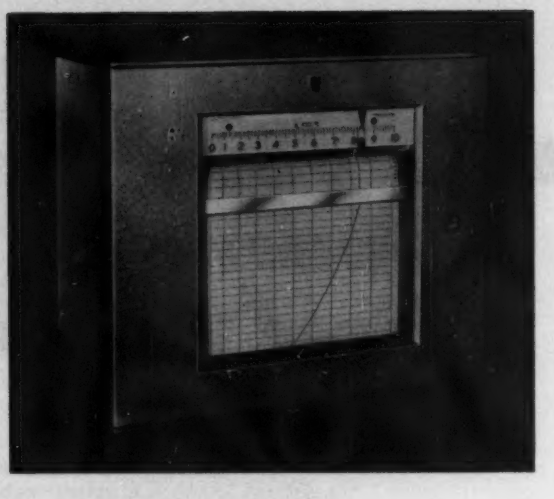
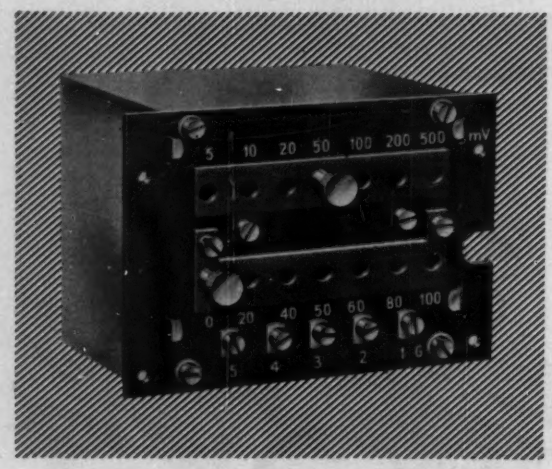


# Easy to change the measuring range in this potentiometric recorder by PHILIPS




*Range-changing unit.* Top rail *permits choice of seven measuring spans from 0-5 mV upwards.* Bottom rail *provides seven zero-point positions up to 100% full scale. Clear, visible indication always.*

Effectively widening the scope of millivolt instruments when employed for experimental work, Philips potentiometric recorders can be supplied with a range-changing unit with provision for no fewer than *forty-nine* measuring ranges! The range is changed *instrument fashion* merely by re-positioning a knurled thumb screw. And you can do this as often as you wish for there are no wander-leads and there is nothing to be soldered. This is only *one* of the many reasons why, point-for-point, Philips potentiometric recorders and recorder-controllers compare so favourably and why too, they are both praised and prized by the most experienced users. From a comprehensive range there is an instrument to meet every need. We invite you to write for fully descriptive literature.

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It is significant therefore that Timken bearings are used on the work-rolls of

## all the wide continuous strip mills in Great Britain

### for the production of Steel Strip

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Ten-stand continuous hot-strip mill
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Continuous hot-strip mill at John Summers, Shotton.

Six-stand continuous hot-strip mill
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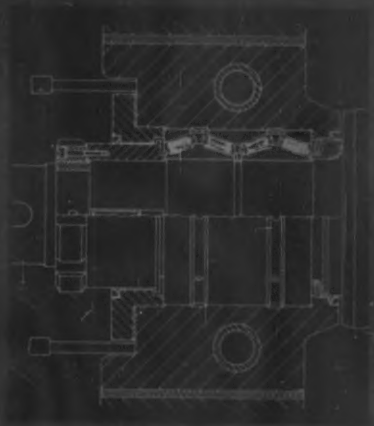
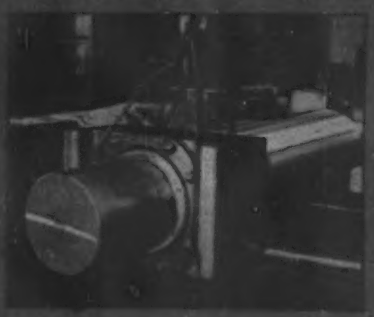
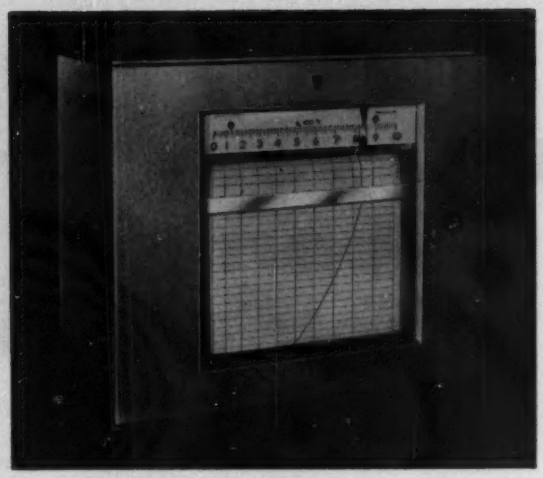


A CHARACTERISTIC INSTALLATION showing the taper engagement



QUICK AND EASY MOUNTING permitted by the loose fit between bearing bore and roll neck



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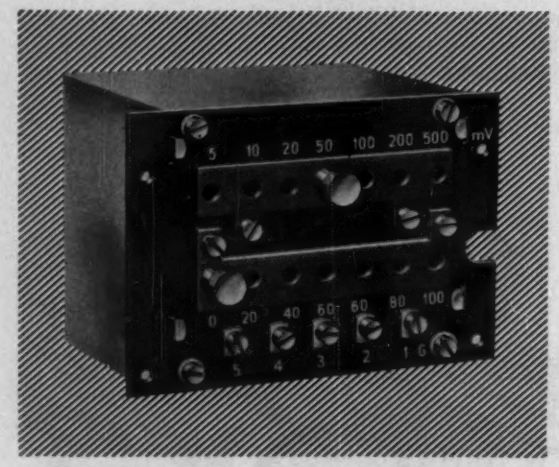


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Five-stand Tandem cold mill and other mills
at The Steel Company of Wales Limited, Velindre.
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**TIMKEN** Regd. Trade Mark

*tapered-roller bearings*

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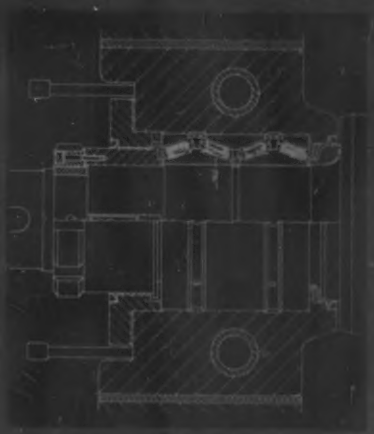
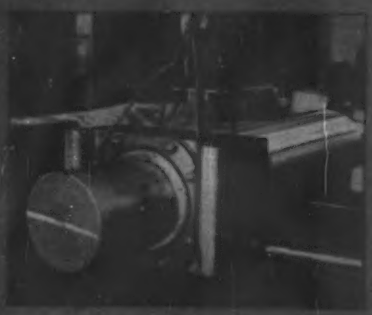


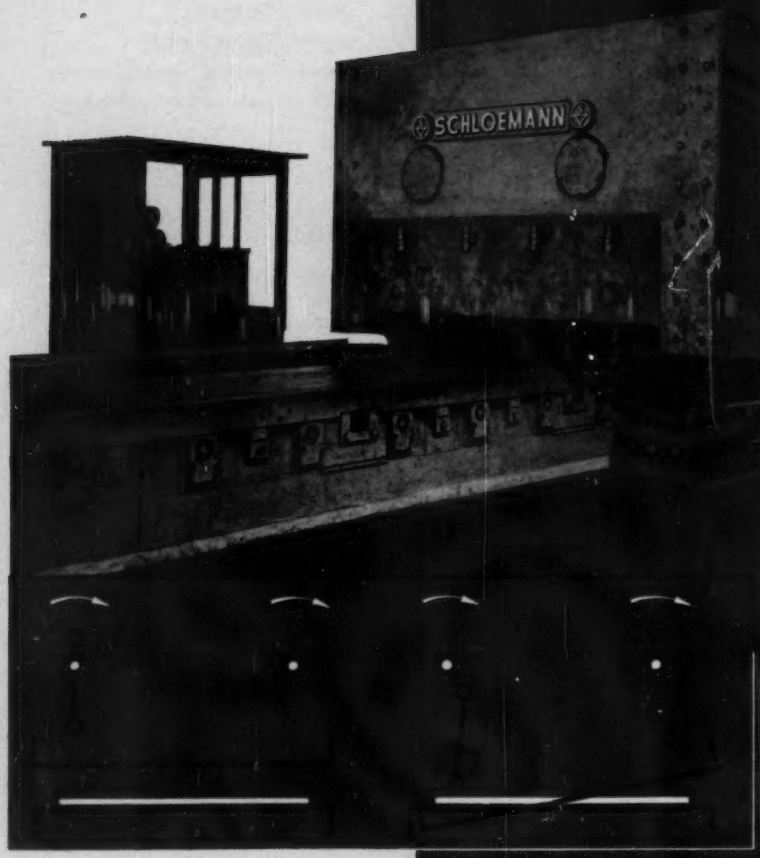
A CHARACTERISTIC INSTALLATION showing the bearings in use.



QUICK AND EASY MOUNTING permitted by the loose fit between bearing bore and cup neck.

# SCHLOEMANN

## Rocker-Type Shear




This shear, for dealing with heavy and medium plate, offers important advantages through its operating principle and design. Outstanding features of proved user appeal are: Large parallel blade gap over entire cutting width facilitates entering and alignment of plates · Rocking-draw movement of top blade produces clean-cut edges when handling plate of any gauge · Since the cutting angle varies during the shearing operation, blade crossing and, consequently, plate distortion is kept to a minimum.

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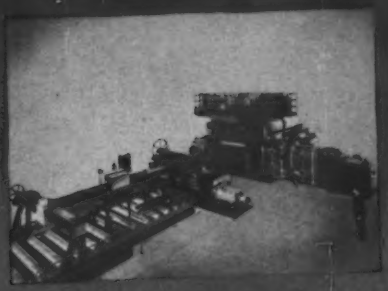

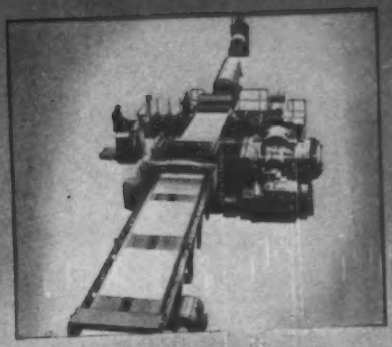

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Today their machinery is in use throughout the world. They are recognised as world specialists and production over 50 years has reached impressive figures.

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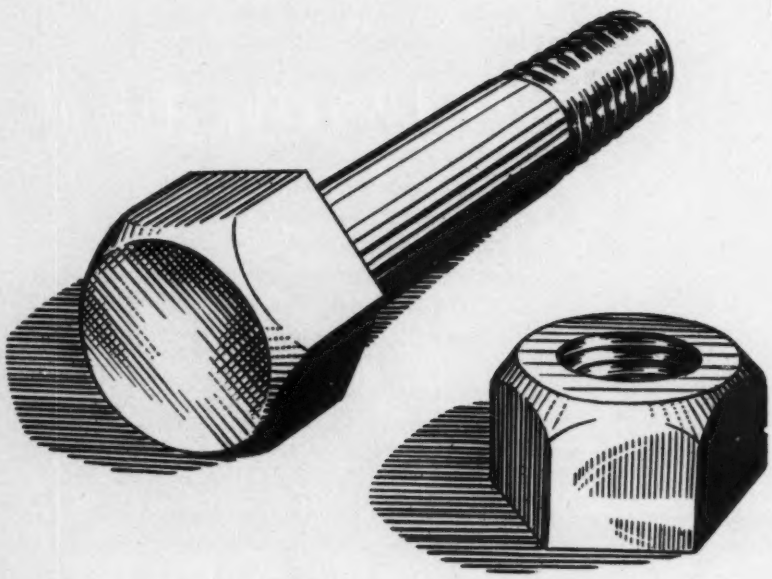

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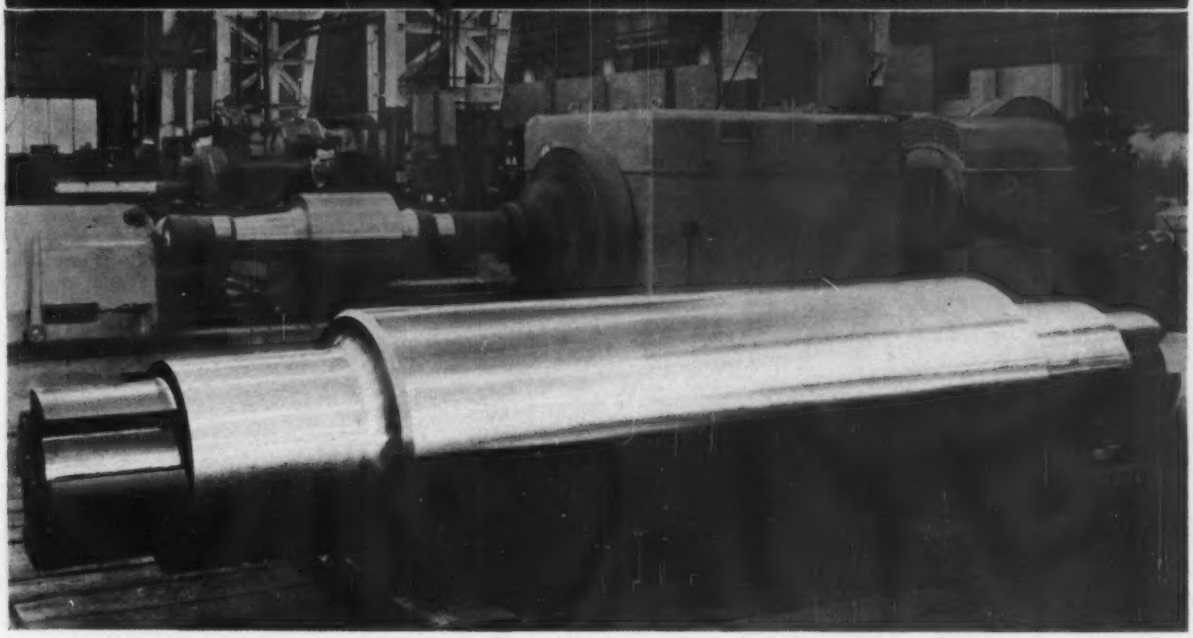

*Hot Plate Mill Finishing Roll, 36" dia. x 108" on the barrel x 203" overall-weight 38,640 lb. each.*

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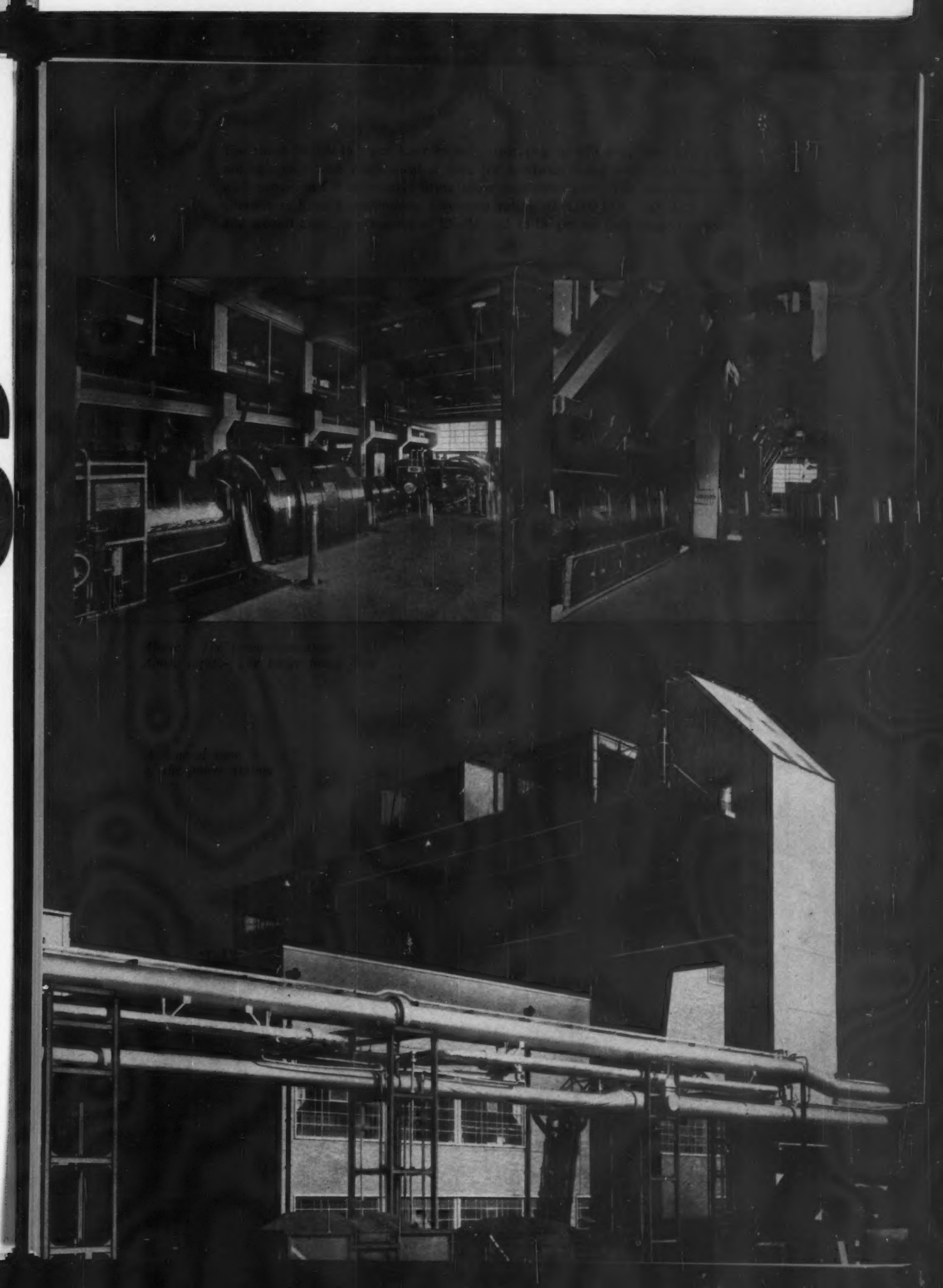

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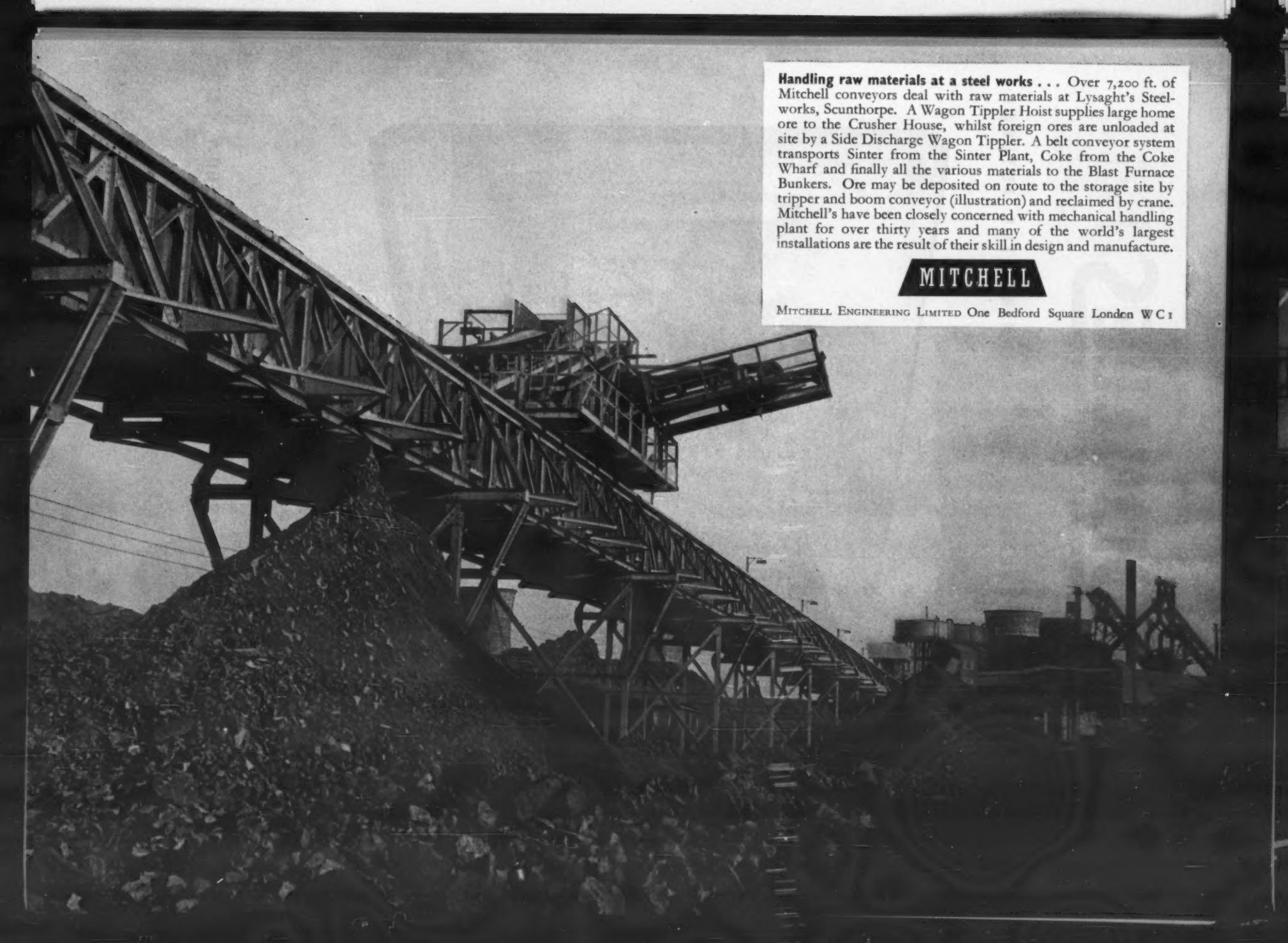

**Handling raw materials at a steel works . . .** Over 7,200 ft. of Mitchell conveyors deal with raw materials at Lysaght's Steelworks, Scunthorpe. A Wagon Tippler Hoist supplies large home ore to the Crusher House, whilst foreign ores are unloaded at site by a Side Discharge Wagon Tippler. A belt conveyor system transports Sinter from the Sinter Plant, Coke from the Coke Wharf and finally all the various materials to the Blast Furnace Bunkers. Ore may be deposited on route to the storage site by tripper and boom conveyor (illustration) and reclaimed by crane. Mitchell's have been closely concerned with mechanical handling plant for over thirty years and many of the world's largest installations are the result of their skill in design and manufacture.

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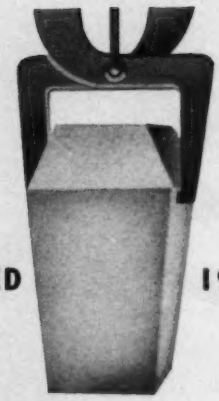

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TGA MP13

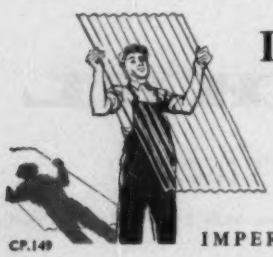
*An interior view of the Corrugated 'Perspex' roof lighting in the factory of Owen & Dyson Ltd., Rotherham. It has been installed over 8 years.*

# Corrugated 'Perspex' installed more than 8 years in iron works, still as efficient as ever

THERE IS no doubt in the minds of Owen & Dyson Ltd., Rotherham, about the lasting qualities of Corrugated 'Perspex'. They installed it over 8 years ago in their factory and they report it is still as efficient as when it was installed.

Of course, there's much more to Corrugated 'Perspex' than just staying power. It is very tough, very light and has high light transmission. It resists weathering and the corrosive atmosphere of most industrial areas. It is easy and cheap to install. Once in, there is an immediate saving of money on artificial light and greater efficiency and better morale among workers.

Corrugated 'Perspex' is made in a wide range of profiles to fit most corrugated roofing materials. If diffused daylight is desired, Opal Corrugated 'Perspex' is available.



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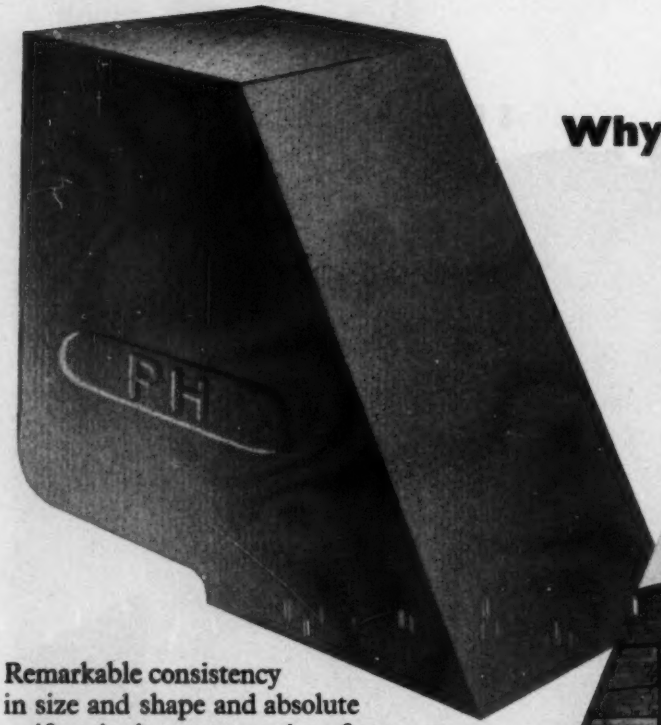


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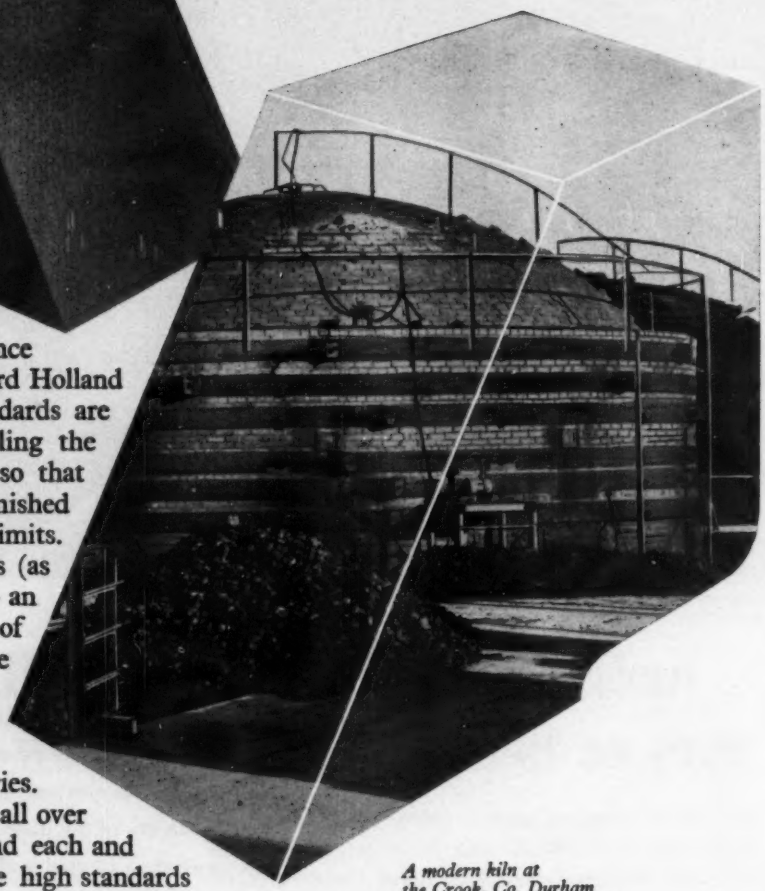

*A modern kiln at the Crook, Co. Durham works of Pickford Holland*

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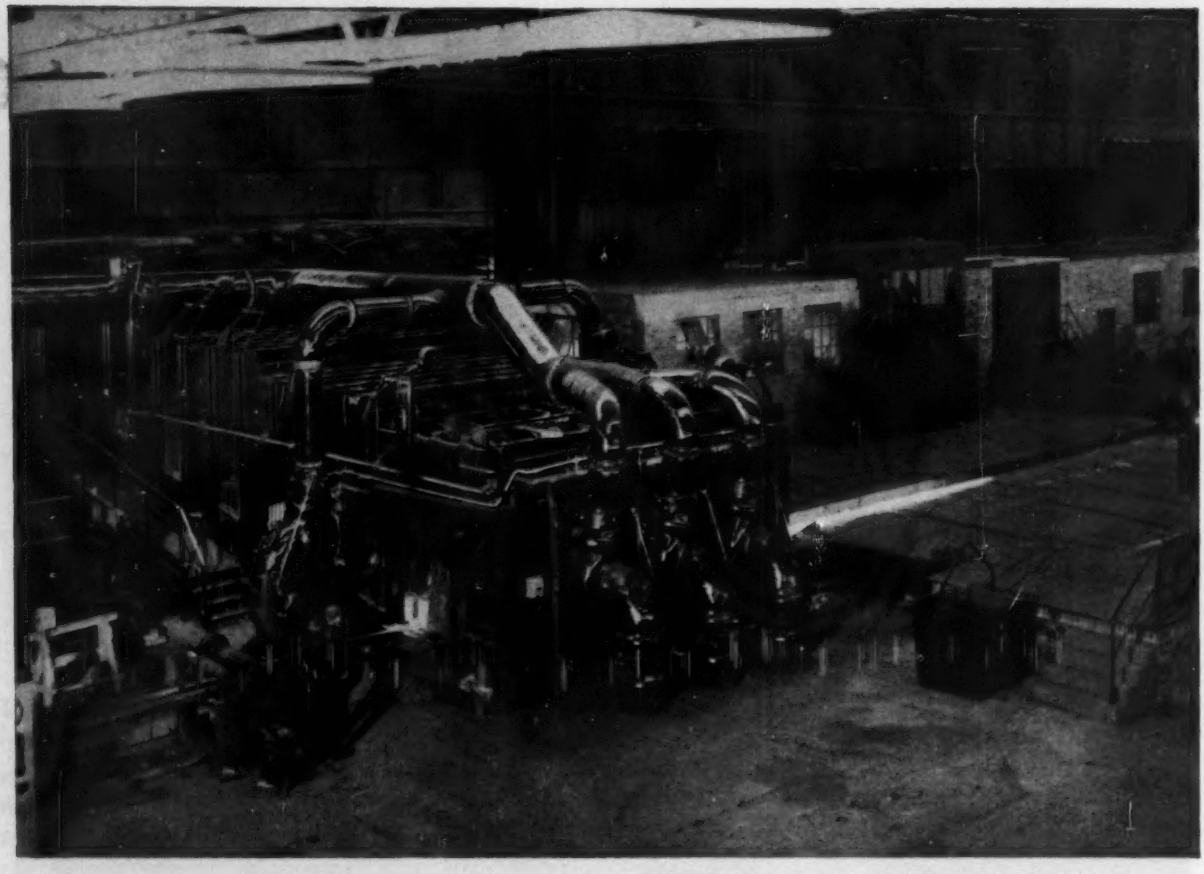

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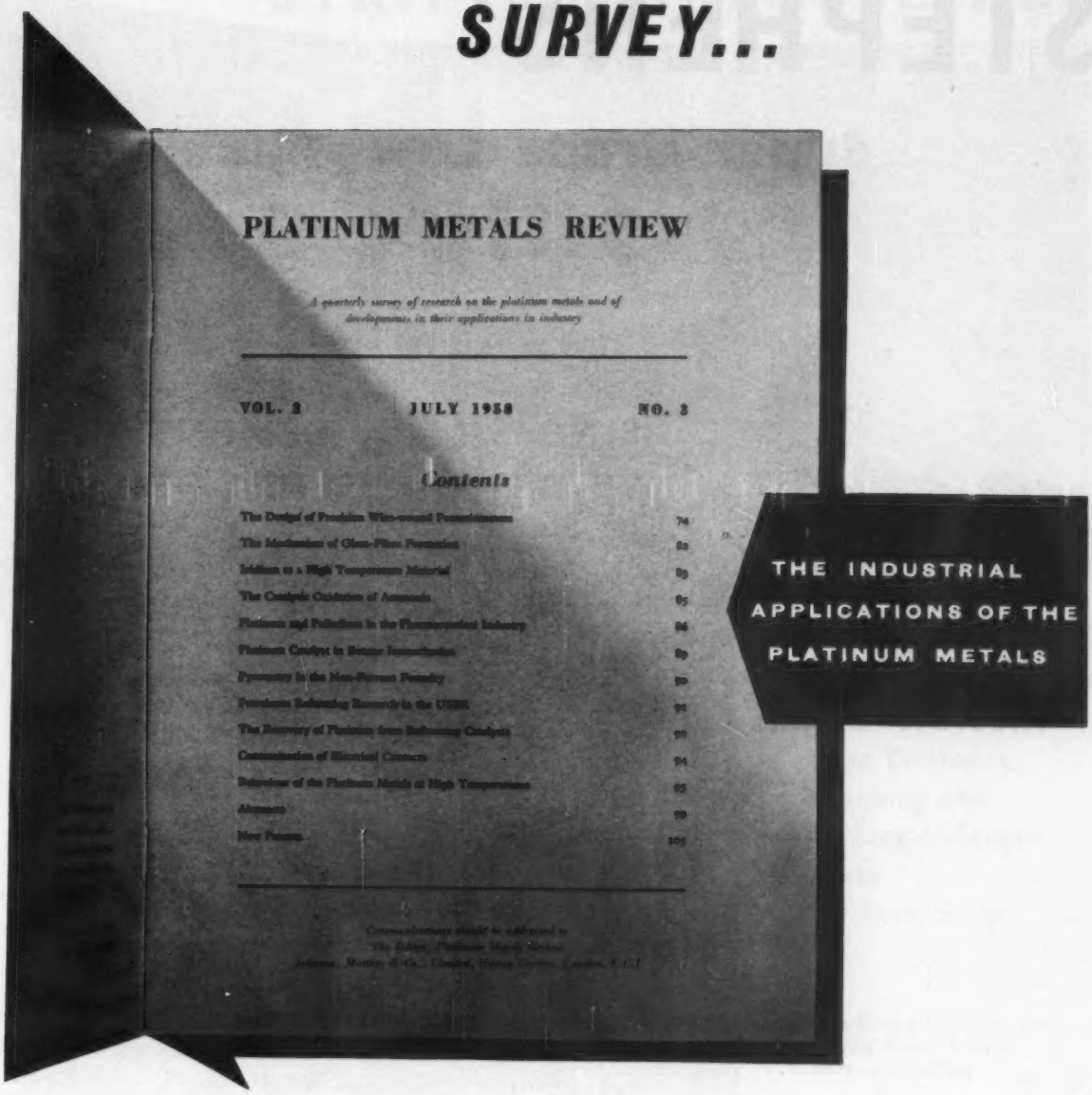
PLATINUM METALS REVIEW
A quarterly survey of research on the platinum metals and of developments in their applications in industry
VOL. 2 JULY 1958 NO. 3
Contents
THE INDUSTRIAL APPLICATIONS OF THE PLATINUM METALS

In recent years the industrial consumption of the platinum metals has increased so rapidly that today nine tenths of all platinum production is absorbed by industry. To provide research workers, engineers, chemists and metallurgists with up-to-date information, "Platinum Metals Review" is published quarterly. May we add your name to our mailing list?

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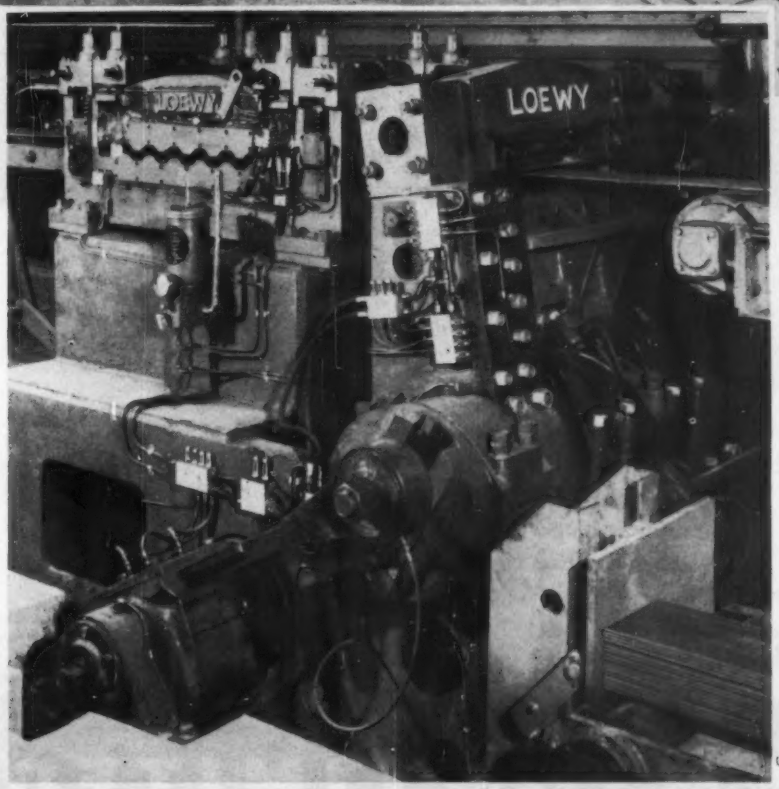


**Edge Trimming, Levelling and Cutting-to-length Lines for Steel Strip**

**Combined Leveller and Flying Shear Unit Patent Pending**

**By courtesy of : Steel, Peech & Tozer, Sheffield.**

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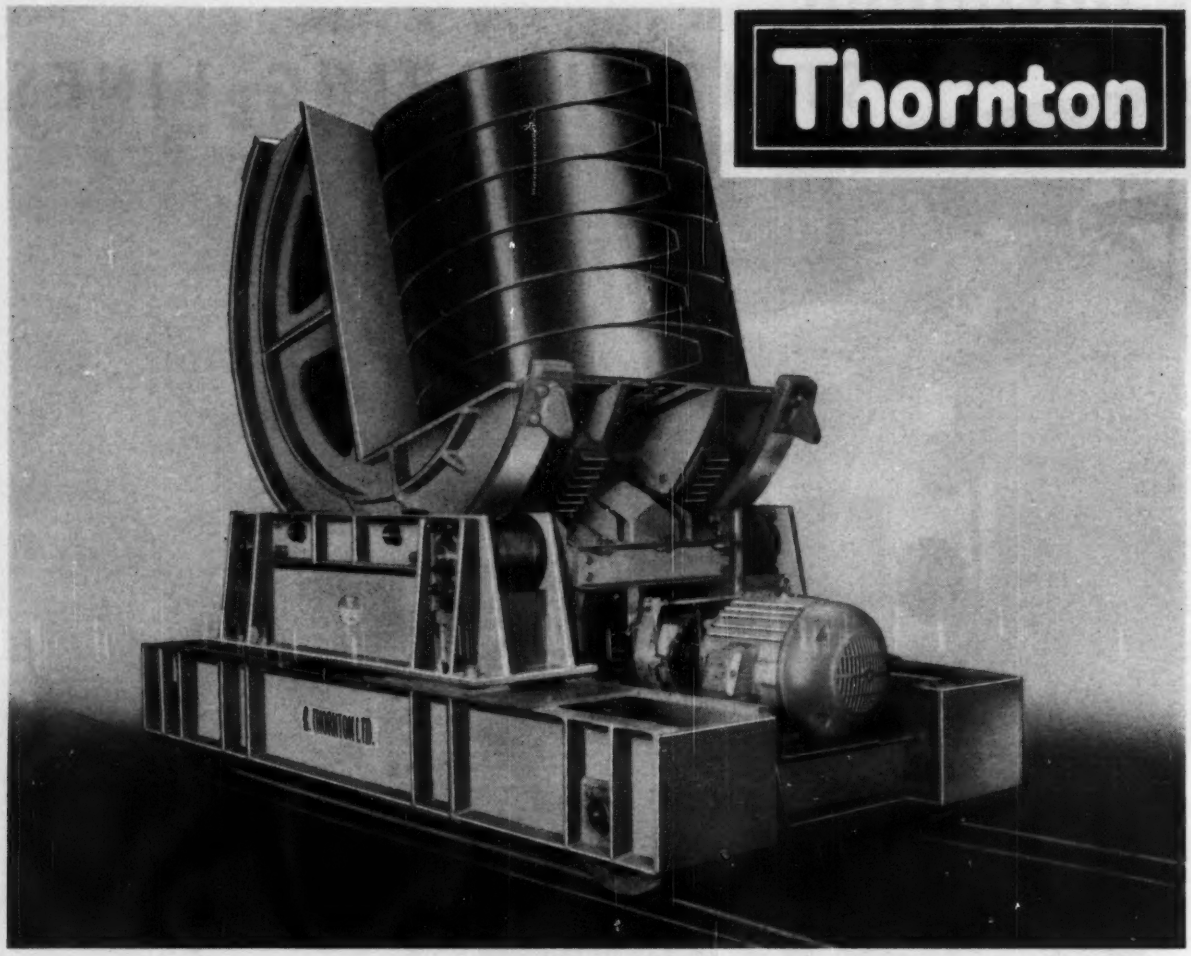


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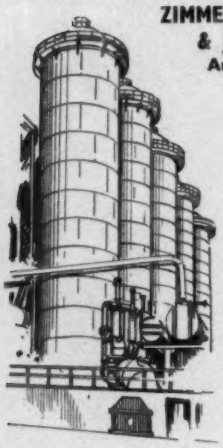
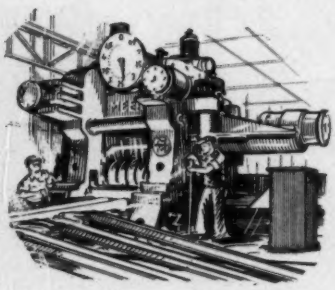
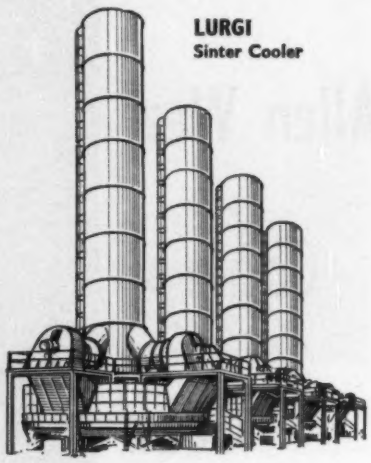


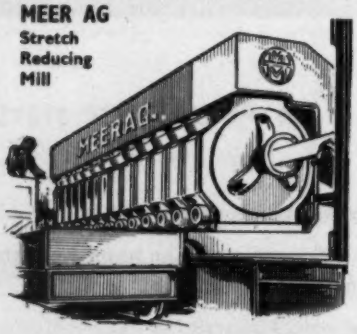
**MEER AG** Plug Mill



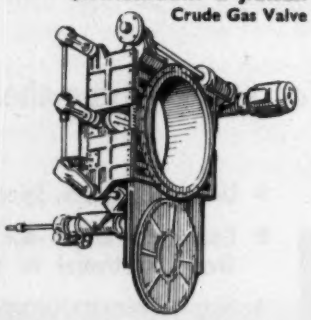
**LURGI** Sinter Cooler



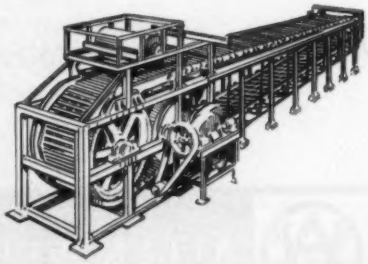
**MEER AG** Stretch Reducing Mill




**ZIMMERMANN & JANSEN** Crude Gas Valve



**LURGI** Sintering Machine



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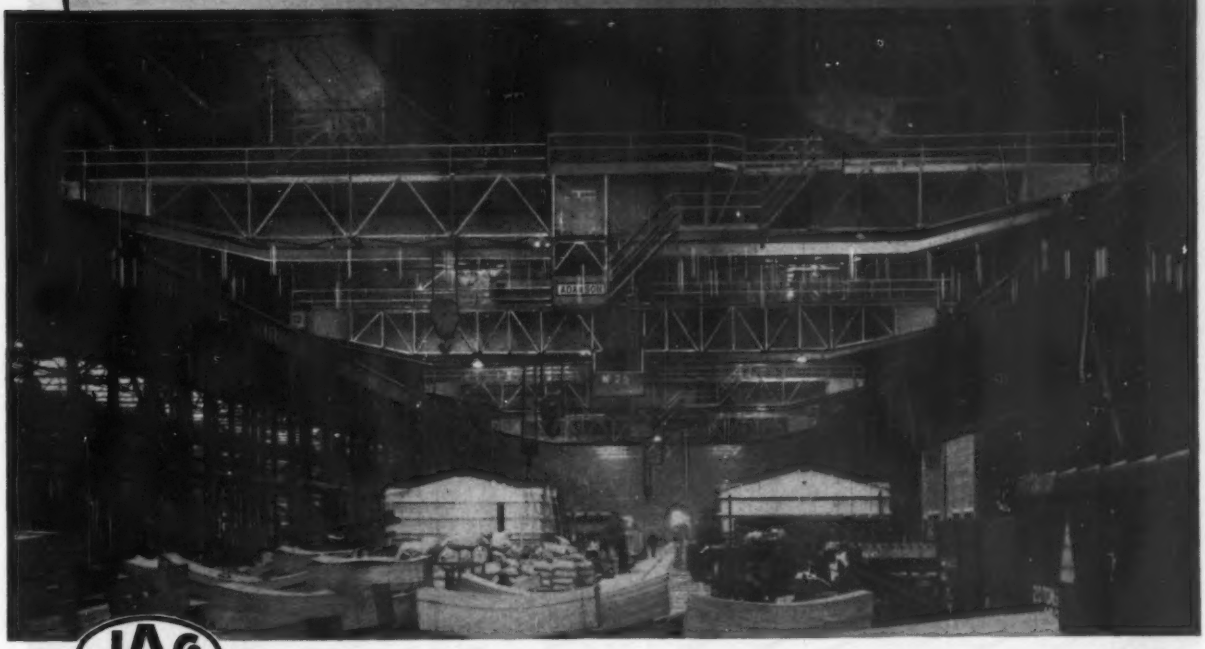

JAC

All Joseph Adamson electric overhead travelling cranes are built to give unfailing service under the most exacting conditions. Generous proportions, provision for easy maintenance and the special attention given to operator control and safety measures are features of Joseph Adamson cranes. Electric overhead travelling cranes can be supplied to all specifications, including cranes suited to the most exacting 24 hours-a-day process work.

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JA.12

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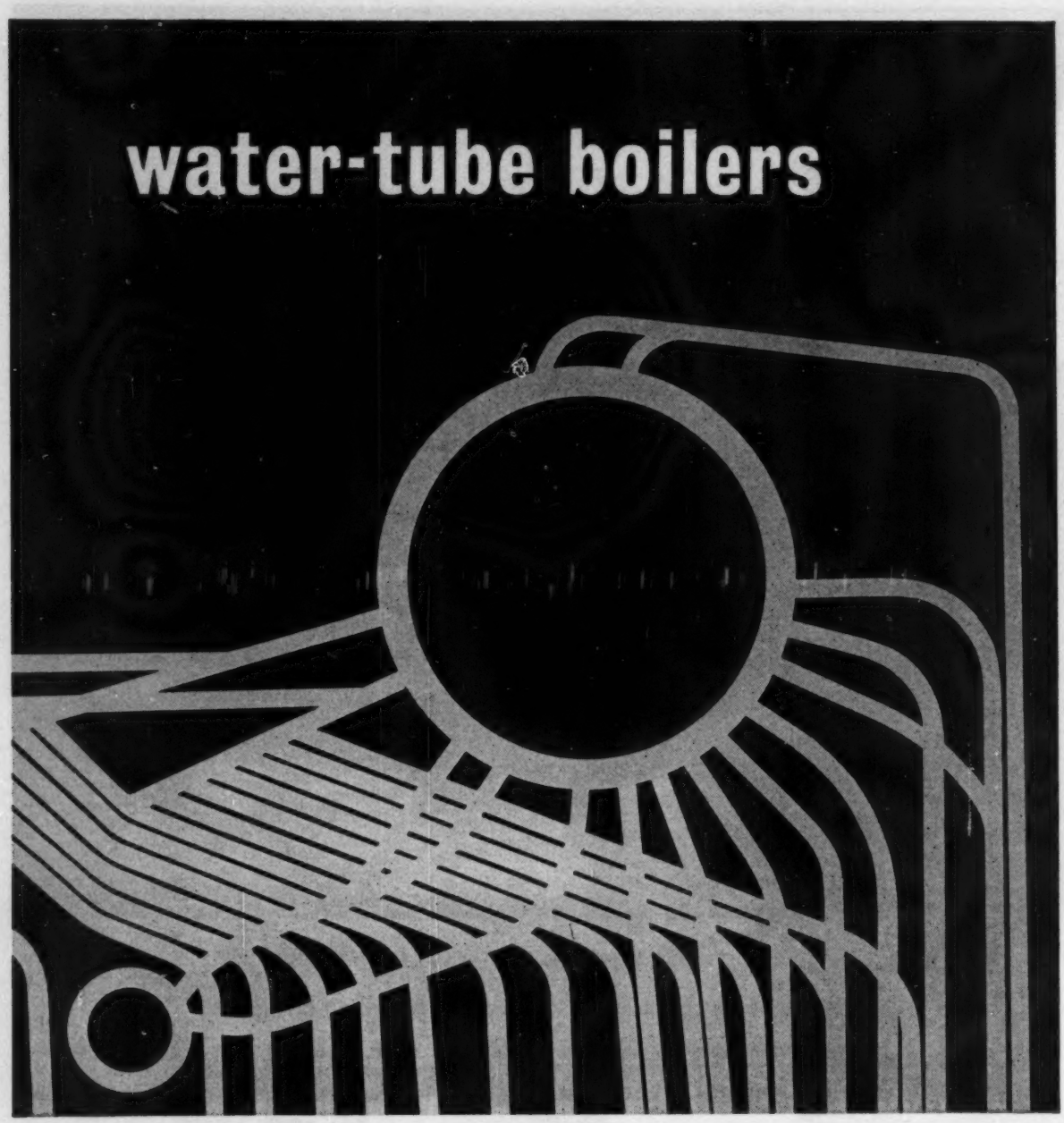

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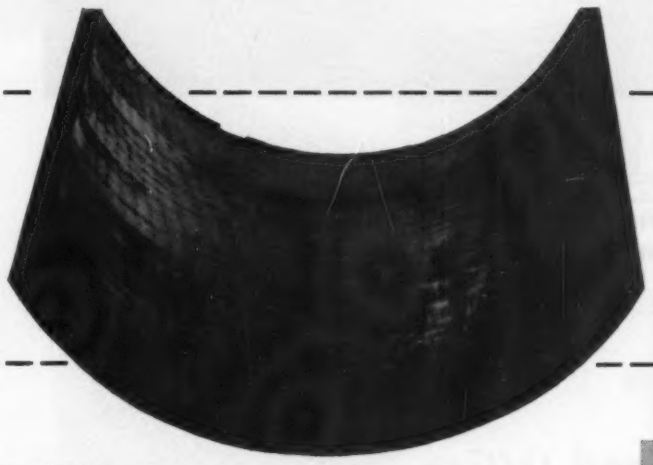

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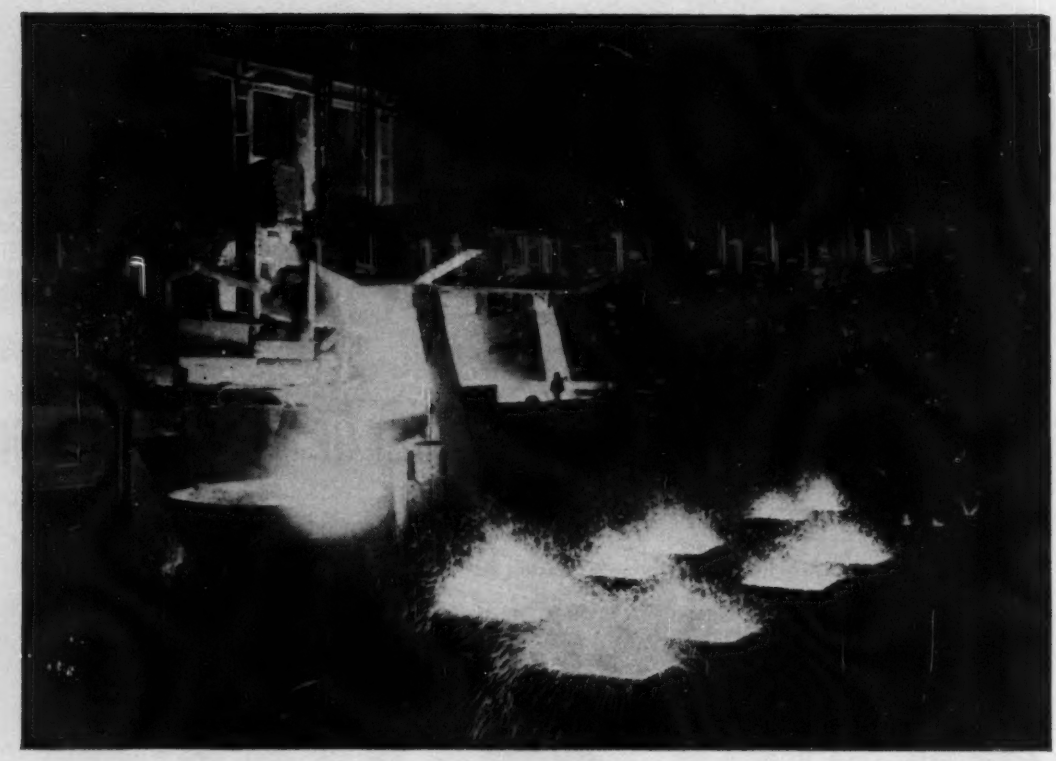

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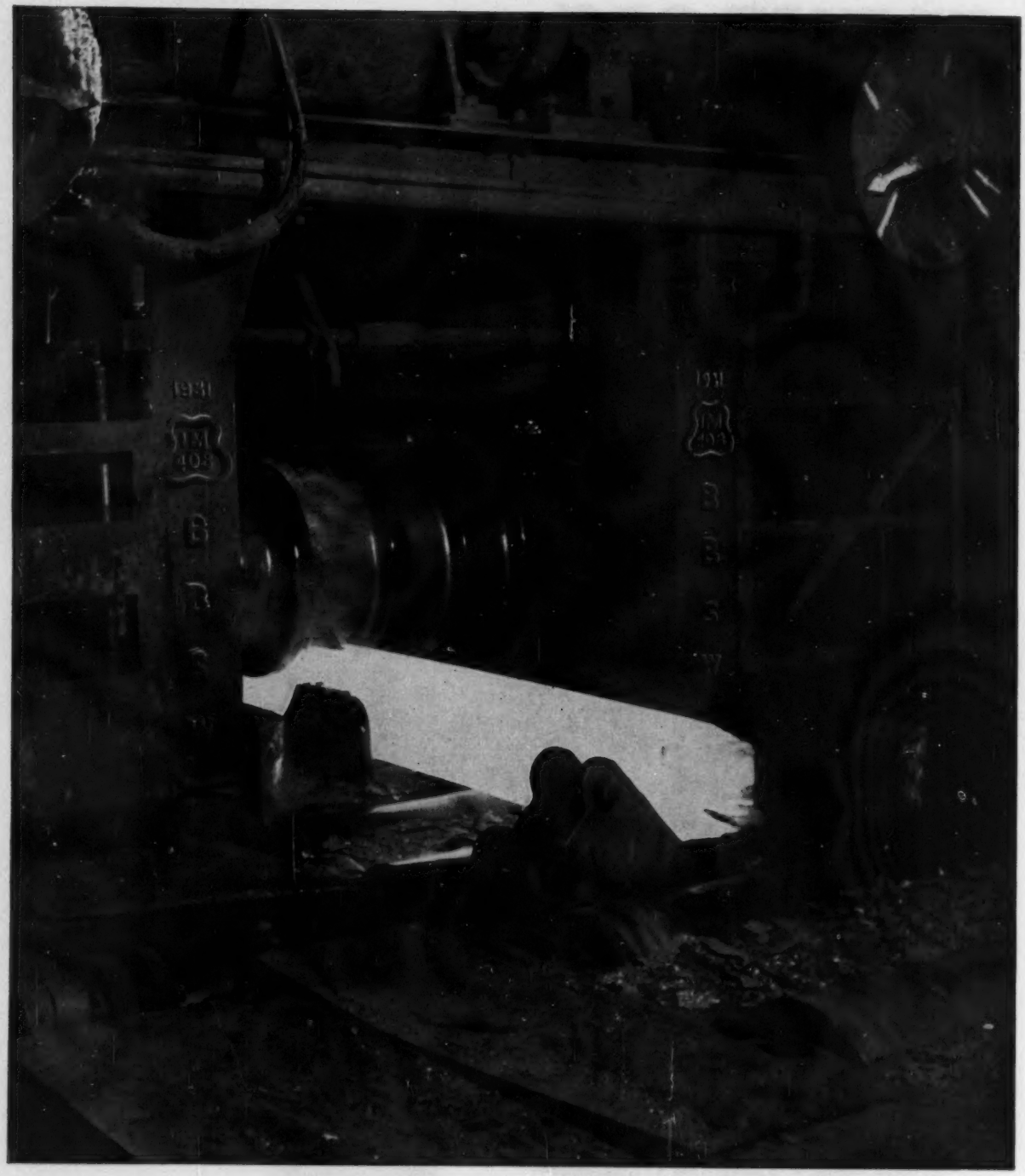

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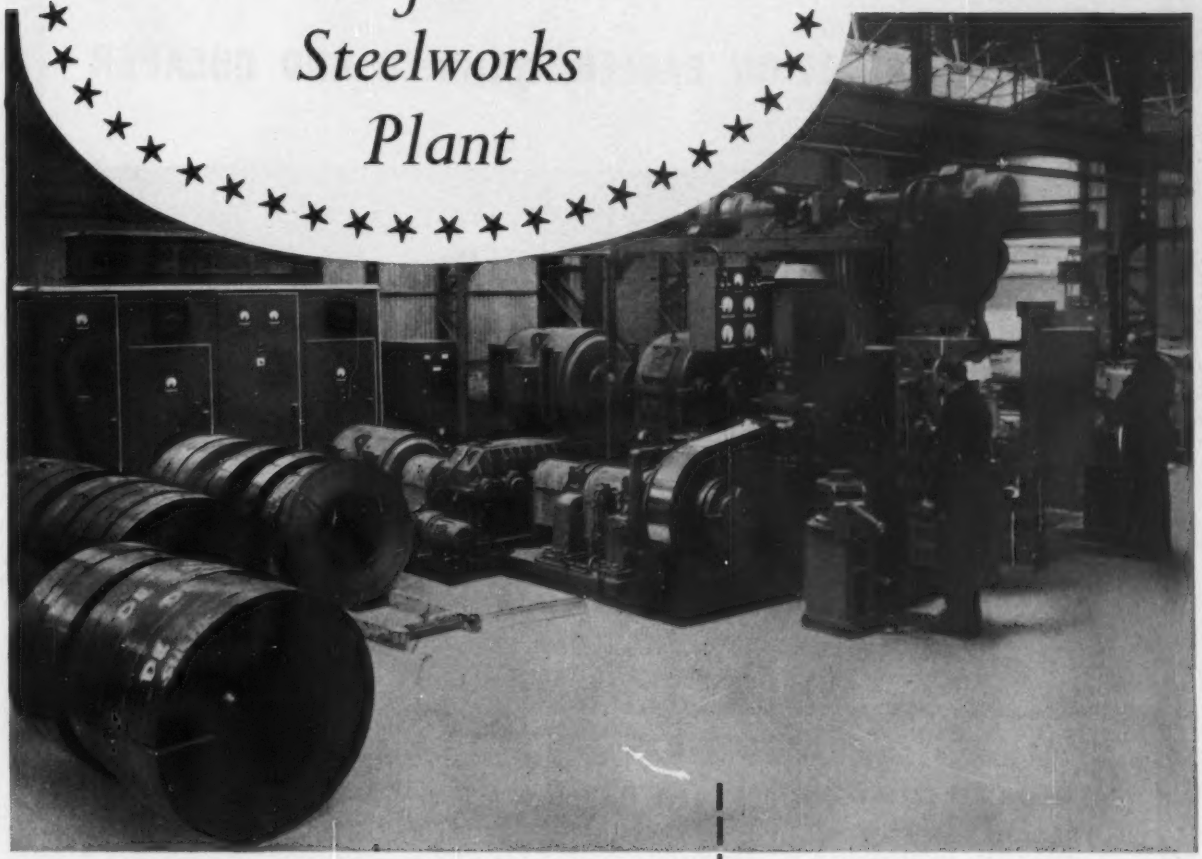

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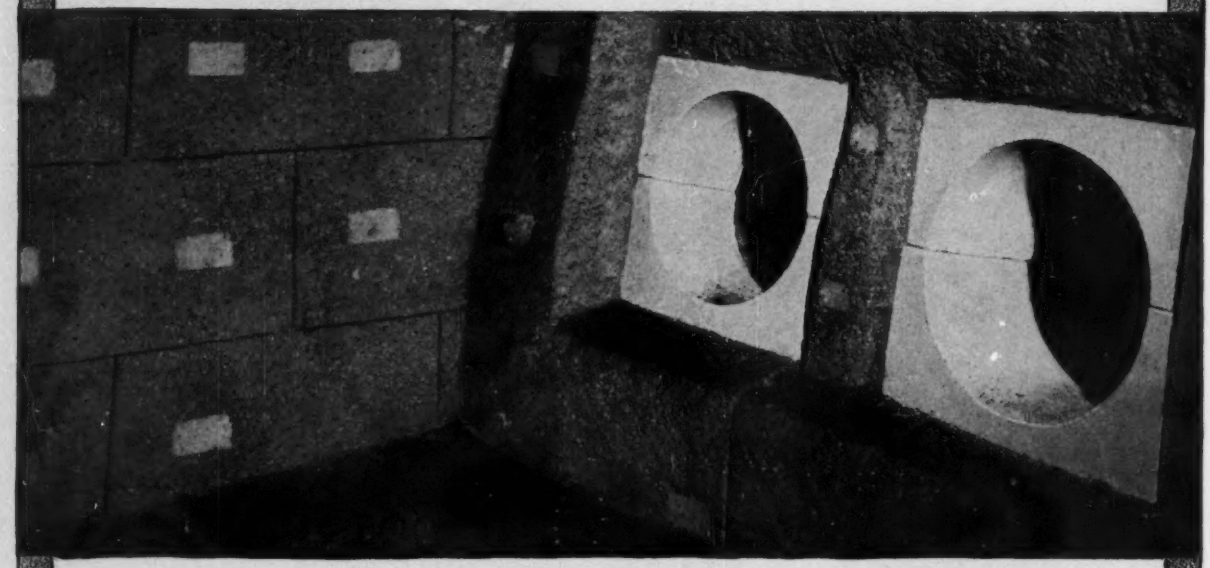

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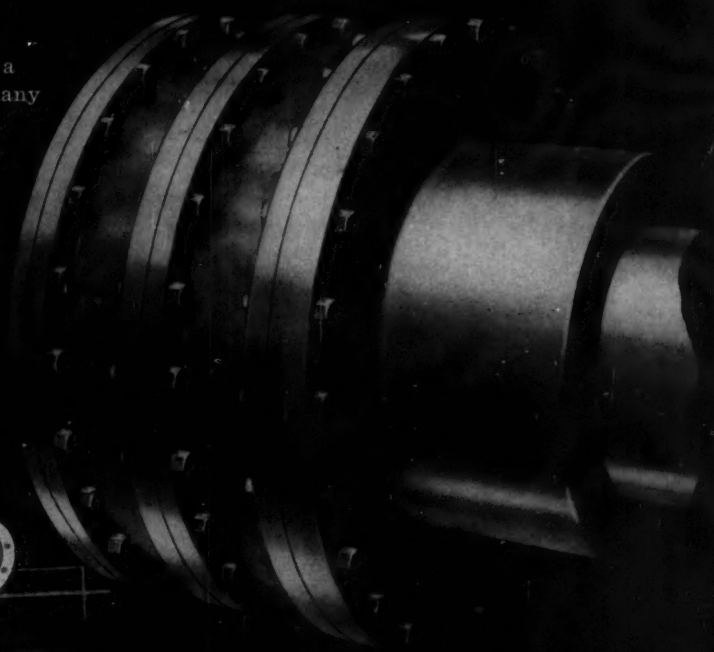

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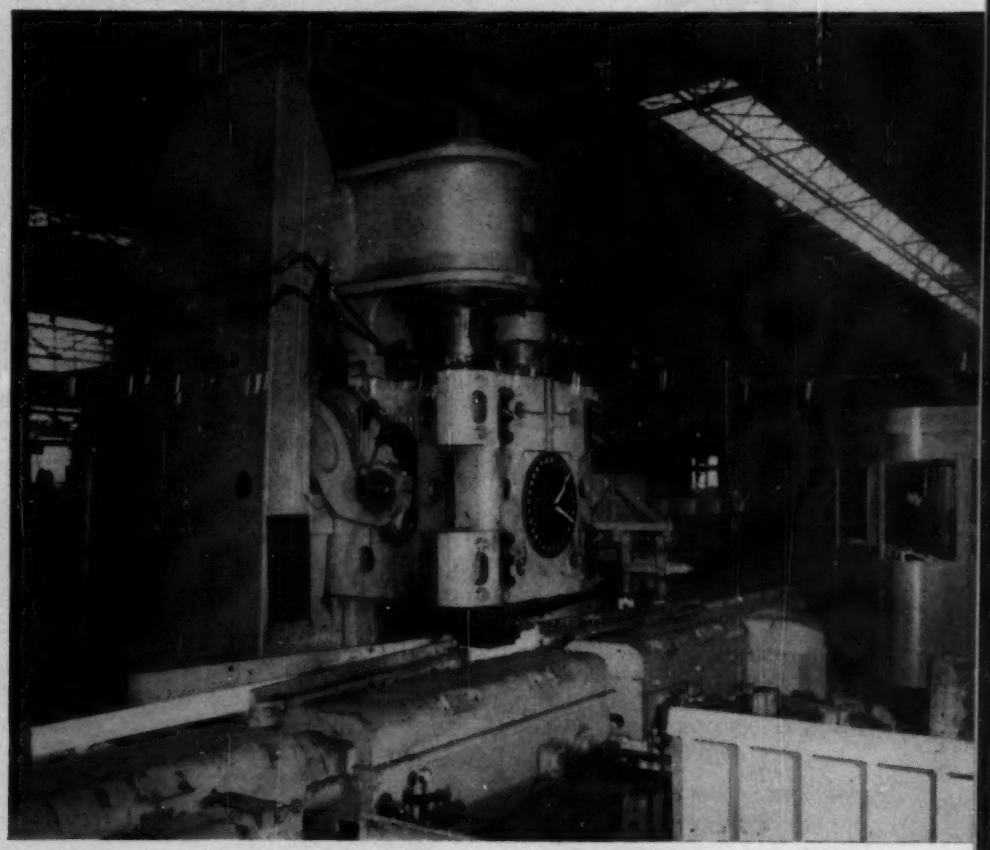

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## N. S. ANGUS, Assoc.Met., A.I.M.

NORMAN STANLEY ANGUS was born in Scarborough and was educated there at St. Martin's Grammar School and at the High School for Boys. He is an Associate in Metallurgy of the University of Sheffield and an Associate of the Institution of Metallurgists.

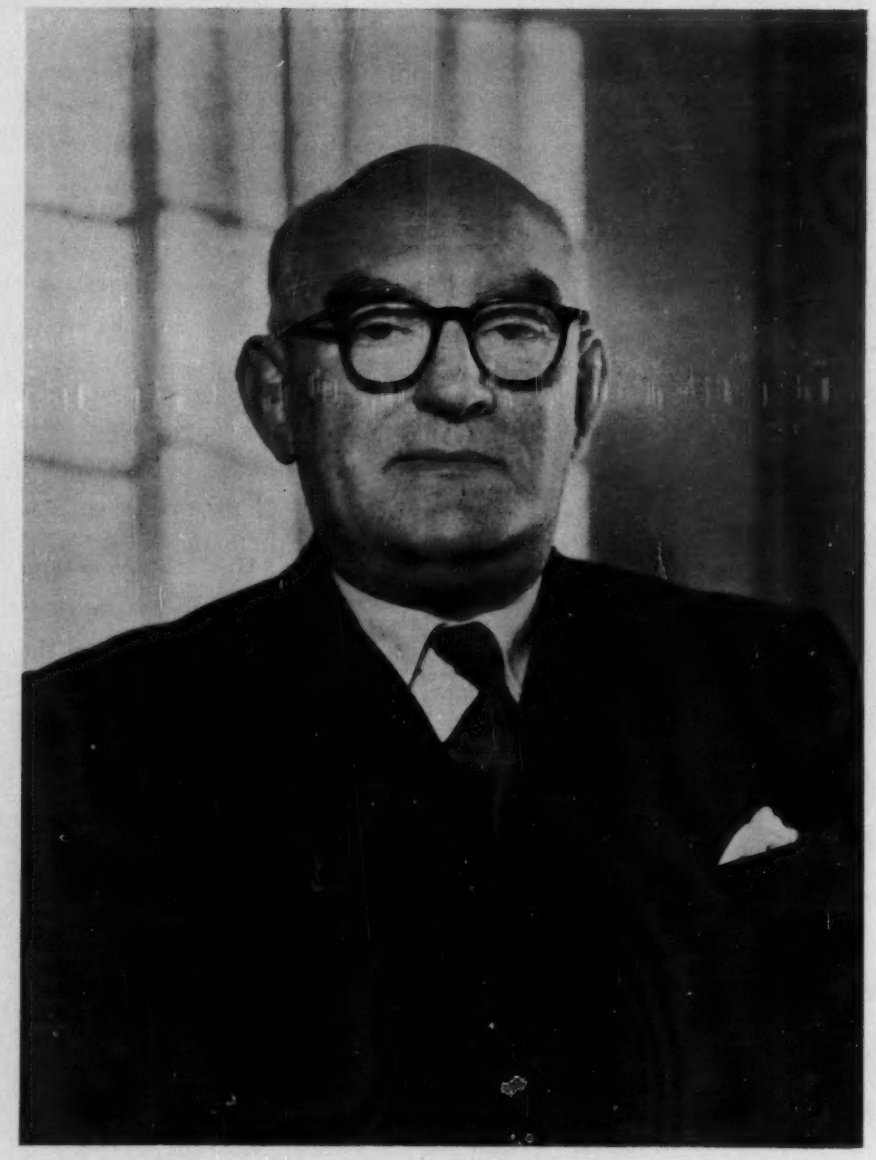
From 1923 until 1929 he was on the laboratory staff at Steel Peech and Tozer, and went from there to Edgar Allen and Co., Ltd., where he stayed for seven years.

After a short period as research assistant in a foundry he became chief chemist and metallurgist with F. M. Parkin (Sheffield) Ltd., tool steel makers, where he remained until 1948.

In that year he joined the Production Engineering Research Association, Melton Mowbray, as metallurgist; he is now in charge of the metallurgical, chemical, heat-treatment, and electro-plating laboratories. The work of the laboratories is very extensive, but particular emphasis is placed on the investigation of metallurgical and chemical factors which influence the machining and forming of metals.

Among other interests, Mr. Angus is a member of the Bibliographical Society and of the Bibliographical Society of Cambridge, and has contributed to the Transactions of the former. He has been a member of The Iron and Steel Institute since 1944.

Mr. Angus has been a member of the East Midlands Metallurgical Society for some years and in 1957 was elected President; he was recently re-elected President for the period 1958–59. When the Society was affiliated to The Iron and Steel Institute, he accepted an invitation to serve as an Honorary Member of the Council of the Institute during his term of office.



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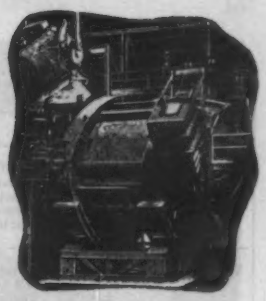


# New Experience in the Continuous Casting of Steel

*By H. Krainer and B. Tarmann*

SYNOPSIS

Two Austrian continuous-casting plants producing sections weighing up to 600 kg/m are described. The construction, life, and cooling of the ingot moulds used at one plant are dealt with.

Descriptions of three methods for studying the cooling of rectangular sections, by cutting the slab near the apex of the cone of solidification, by the addition of radioactive phosphorus or sulphur, and by the addition of lead, are followed by data on the rates of casting that can be achieved. The cutting up of slabs and a consideration of their internal and external defects lead finally to a description of the dangers of using superheated metal and of irregularities in cooling. 1617

## INTRODUCTION

THE FIRST ATTEMPTS to cast steel continuously were probably those made in Austria in 1934 by Bleckman,[1] but they were not regarded as successful. During World War II the question of continuous casting was studied by Gebr. Böhler and Co. A.G. of Kapfenberg, but at the time the intended trials could not be carried out. In 1947 a Consortium for research into and development of continuous casting was founded by Oesterreichische Alpine-Montan Gesellschaft, Gebr. Böhler and Co. A.G., Eisenwerk Breitenfeld G.m.b.H., Schoeller-Bleckmann Stahlwerke A.G., and Vereinigte Oesterreichische Eisen u. Stahlwerke A.G., and trials were begun at the works of Schoeller-Bleckmann. Early in 1948 trials were continued at the works of the firms Eisenwerk Breitenfeld G.m.b.H. and Gebr. Böhler and Co. A.G. Edelstahlwerk, Kapfenberg. From the autumn of 1948 development work was concentrated on the Kapfenberg Alloy Steel Works, where systematic and fundamental trials were carried out on the continuous-casting process. Krainer and Tarmann[2, 3] published data covering the most important results obtained in tests on solidification processes in continuous casting and heat transfer in the mould, together with information regarding the properties of special steels produced by the continuous-casting process. Following a joint decision by the firms interested in development, Böhler then erected a plant for casting small and medium melts, making use of all the experience which had been gained. The basic features and most important constructional characteristics are embodied in the plants which have been working since March 1952 at the Edelstahlwerk Kapfenberg and since early 1953 at the Eisenwerk Breitenfeld.

An agreement concluded in 1952 with the Stahl-Stranggiessgemeinschaft Deutschland (The Continuous Casting Association of Germany), which had at its disposal the experience gained by Junghans and the Mannesmann A.G., led to a close technical co-operation between these groups.

## PLANT DESIGN

The design of the Austrian continuous-casting plants has been made known by a large number of patents held by Gebr. Böhler and Co. A.G.[4] The Kapfenberg plant has been described by Hofmaier.[5] A prominent feature is the separation between working and machine areas (cold side) and casting area (hot side). This means, on the one hand, that there is extensive protection for personnel and machines, whilst on the other hand, the strand is under observation from the moment it leaves the mould until it is sheared, so that adjustments to the casting conditions can be made rapidly. A further characteristic of the Austrian design of continuous-casting plant is the lowering gear which consists, for each strand, of two pairs of overhung rolls which are all driven and which automatically adjust themselves to different sections of strand.

In the continuous-casting plant at Kapfenberg strands of 100–600 kg/m weight are cast. The

This is a slightly abridged version of the paper presented at the 10th Technical Session in Charleroi of the Journées Internationales de Sidérurgie.

The authors are with Gebr. Böhler and Co., A.G., Kapfenberg, Austria.

**Table I**

**PRODUCTION PROGRAMME FOR KAPFENBERG CONTINUOUS-CASTING PLANT**

| | Section, mm<br>Pouring rate, m/min | 130 dia.<br>0·8–1·2 | 200 dia.<br>0·5–0·6 | 120 square<br>1–14 | 360–230<br>0·35–0·55 | 330–100<br>0·8–1·25 | 500–110<br>0·6–1·15 | 370–170<br>0·55–0·90 |
|---|---|---|---|---|---|---|---|---|
| Structural steels | Unalloyed charge and steels for hardening and tempering | X | X | X | O X | X | X | X |
| | Alloyed charge and steels for hardening and tempering | X | X | X O | O X | X | X | O X |
| | Spring steels | X | | X | X | X | X | X |
| Tool steels | Unalloyed | | | | | X | X | O X |
| | Alloyed | | | | | X | X | O X |
| | Highly alloyed (i.e. 2% C, 12% Cr) | | | | | X | X | |
| | High-speed steel | | | | | O X | O X | |
| Chemically stable steels | Austenitic Ni–Cr | | | | | O | O X | |
| | Rustless Cr steel | | | | | O | O X | |
| | Austenitic heat-resisting steels | | | | | O | O | |
| | Austenitic Mn steels | | | | | X | X | |

X Current production O Developments

Experimental moulds are in use for 200 mm × 150 mm slab at a pouring rate of 0·6–0·8 m/min

mould can be changed within an hour if a different section is to be cast. This is extremely useful in a mixed programme. The plant described by Leitner[6] at the Eisenwerk Breitenfeld G.m.b.H. Wartberg, Mürztal, is used for strand weights up to 150 kg/m. It was possible, therefore, for it to be built on lighter and more economical lines.

The moulds for the Böhler and Breitenfeld plants are made from seamless or welded copper or copper-alloy tubes with wall thicknesses of 10–15 mm. For lubricating the moulds[7] oil is metered during casting by a pump which delivers to the flange of the mould through a groove with openings at intervals, so that an even film of oil is deposited on the internal surface of the mould. A specially shaped mould bottom, required when casting is begun,[8] is kept on hand in the plant. The secondary cooling stretch is equipped with adjustable spray cooling. For some strands a roller cage is also used. There is an instrument stand with apparatus for measuring temperatures, speeds, and quantities, and also pressures.

## SECTION AND TYPE RANGES

At Breitenfeld the strands are of smaller section, these being 130 mm dia., 110 mm dia., 96 mm square and 115 mm × 86 mm and 275 mm × 65 mm. Most of the steels cast are plain carbon steels with up to 0·85%C, and also slightly alloyed structural steels. It is worth noting that the greater part of the steel produced in these works in a 4-ton and a 10-ton arc furnace was cast in the continuous-casting plant.

At the Böhler works the section and quality programme for continuous casting is very extensive. The continuous-casting plant set up in the electric steel plant is fed with 7–8-ton casts. Its task, in addition to actual production, was to determine the conditions required for the continuous casting of various types of alloy steels in a large number of sizes, this investigation being carried out under working conditions and in such a way that the results could be transferred direct to larger plants. The most important sections of strand in the types of steel which are in current production or still undergoing trial are shown in Table I.

This great number of different sections is necessary to meet the requirements of other departments. In the sheet rolling mill, which takes the greater part of the current production from continuous casting, sections 330 mm × 100 mm, 500 mm × 110 mm, and 370 mm × 170 mm are used successfully in the types of steel shown in Table I, the section being determined by finished size and weight, and by type of steel.

Drop forgings and pressed parts are for the most part produced from round strands, and, where the pieces are very heavy, from 230 × 360 mm material. The direct use of continuously cast billets in the forging department is worth noting from the viewpoints of economy because of the amount of rolling work which is saved; several thousand tons of forgings produced from continuously cast material have proved successful.

The 360 mm × 230 mm and 370 mm × 170 mm sizes are worked down to bar steel on the ingot and roughing mill, whilst the 120-mm square size is mostly used for the production of laminated springs.

## ASPECTS OF THE TECHNOLOGY OF CONTINUOUS CASTING

It is impossible in this paper to cover the whole field of continuous casting: only a few problems have been chosen for discussion.

### Movement of Moulds

Stationary water-cooled moulds were at first used at Kapfenberg. With stationary moulds, however, the demands made on lubrication were very heavy. This again demands low temperature on the internal walls of the mould, which can be attained by thin mould walls and, at the same time, intensive cooling, favouring high rates of casting. If there is any warping of the shell of the strand owing to irregularities, however, this leads to the strand resting against one side of the mould, which can cause an increase in the amount of material rejected, especially in sensitive steels. Lubrication must be so effective that the metal surface is always convex in shape, that is to say the wall of the mould must not be wetted by the steel if sticking and tearing of the strand are to

be avoided. A marked improvement is obtained compared with the stationary mould when spring suspension is provided for the mould,[9] but in many cases this is not sufficient. In 1933 Junghans[10] recognized that it is advantageous for the relative movements of strand and mould to be interrupted. The problem was solved in the following way; for a period the mould moves with the strand and is then returned to its original position at increased speed. The advantage of this process is that the rate of withdrawal can be kept constant, the disadvantage is in making cooling connections, etc., to a moveable mould. Intermittent lowering of the strand requires special switch gear and has the drawback, especially where large sections of strand are concerned, that a very considerable mass has to be constantly accelerated and braked. It has the advantage, however, that if the height of the level of cast metal is under supervision, for example, by means of a thermocouple[11] it can be developed into an automatically regulated continuous-casting process.

Both processes were tested thoroughly at Kapfenberg. At the moment the authors are of the opinion that the Junghans moveable mould is more likely to satisfy the requirements, even if the movement of the mould originally proposed by Junghans is replaced by a sine-form movement.

As in ingot casting, the parting of the strand, especially in the larger sizes, from the mould results in a reduction in the amount of heat transferred to the mould and causes the surface of the strand to become too hot. Figure 1 shows the mould for a 500 × 110 mm slab: to determine the temperature distribution on the copper mould salts were added to the cooling water. These separated out when the outer wall was at 70° C. It will be seen that on the narrow faces, where the effect of shrinkage is particularly marked, the cooling effect decreases rapidly. It is advisable, therefore, especially in the case of larger sections, to use inverted conical moulds. Not only is the casting output increased but a better surface is obtained.

### Life of Moulds

The relatively thin-walled moulds used show no noticeable signs of wear even after several thousand tons have been cast, if mould warping is eliminated by repair work carried out at suitable intervals. The 500 mm × 110 mm slab moulds were trued up after about 100 casts.

### Thermal Capacity of Moulds

Whilst it is still in the mould the strand should form a solidified shell thick enough to permit the strand to be safely handled outside the mould. This wall thickness should amount to 15–25 mm (average about 20 mm) according to the section being cast. The heat quantity $W_s$ to be carried away by the mould per square metre of strand surface amounts to 8000–12,000 kcal/m² for a solidified shell about 20 mm thick at the end of the mould. The cooling capacity of the moulds is as follows:

$$Q = W_s U V \quad \ldots\ldots (1)$$

where $Q$ = Cooling capacity of mould, kcal/min
$U$ = Circumference of mould, m
$V$ = Rate of casting, m/min.

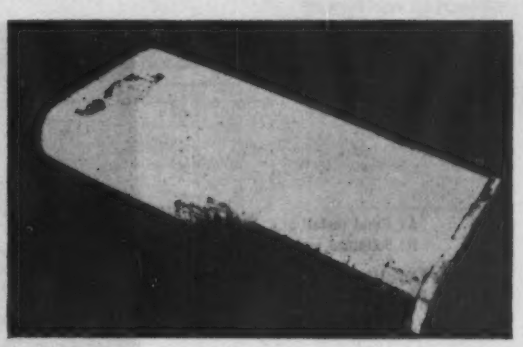


Fig. 1—Uneven salt deposits on surface of mould

The average specific cooling capacity of the moulds ($q_s$) should therefore lie at about 12,000–20,000 kcal/m² in the utilized part of the mould, although higher cooling capacities can be obtained in the mould under special conditions.

The minimum length of the mould is as follows:

$$L_{min} = \frac{W_s}{q_s} V \quad \ldots\ldots (2)$$

$L_{min}$ must be increased, owing to unavoidable operational factors, by a safety factor $z$ so that a more reliable length $L_B$ may be obtained.

$$L_B = L_{min} + z \quad \ldots\ldots (3)$$

Larger relative lengths of mould $L/V$ lead to more extensive solidification in the mould, if suitable heat transfer is attained by the correct choice of conicity in the mould. Mould lengths which are too large, just as those which are too small, lead to difficulties of a mechanical or metallurgical type.

The amount of cooling water $M$ is found as follows:

$$M = \frac{W_s U V}{\Delta t} \quad \ldots\ldots (4)$$

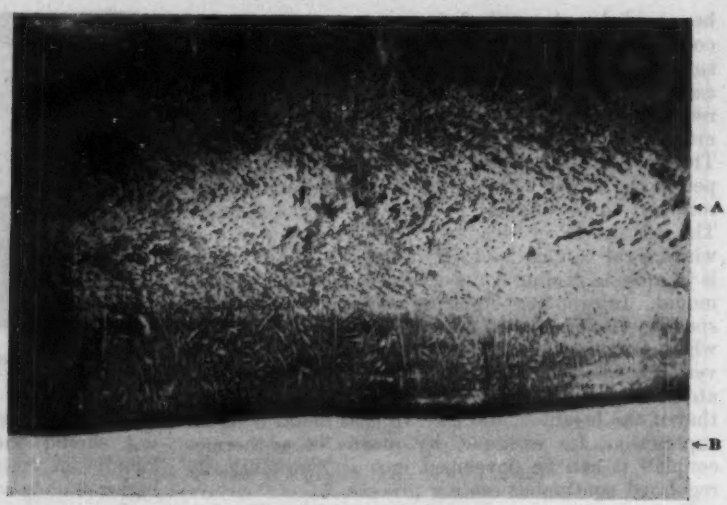
where $M$ = Quantity of cooling water, l./min
$W_s$ = Specific heat supply, kcal/m²
$U$ = Circumference, m
$V$ = Rate of drop, m/min
$\Delta t$ = Permissible increase in temperature of cooling water, ° C

The permissible increase in temperature of the cooling water on passing through the mould amounts to 2–10° C. If a closed circuit is used, which is advisable, water temperatures up to about 60° C may be used with suitable softening treatment when adequate quantities of clean soft water are not available. Metallurgical difficulties initially encountered were due to hydrogen and were eliminated by controlling the cooling water temperature.

It will be seen from equation (1) that the heat quantity per kilogramme of steel lost to the mould is as follows:

$$q_K = \frac{W_s}{\gamma} \times \frac{u}{f} \quad \ldots\ldots (5)$$

where $q$ = Heat quantity transferred to mould per 1 kg steel, kcal/kg
$W_s$ = Specific heat removal, kcal/m²
$\gamma$ = Density, kg/m³
$u$ = Circumference, m
$f$ = Cross-sectional area, m²




A: Fluid metal
B: Solidified metal

**Fig. 2—Longitudinal radiograph of slab with $^{32}P$ added**

Since $W_s/\gamma$ is practically constant, the quantity of heat given off per kilogramme of steel at a given shell thickness is dependent on $U/f$.

As is shown later the rate of solidification satisfies, at a first approximation, the relation:

$$s = c\sqrt{t_K} = c\sqrt{\frac{L}{V}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where $c \sim 25$–$30$ mm/min, in slabs
$t_K$ = Time in passing through the mould.

This equation also shows that with smaller shell thicknesses higher casting rates are obtained on short mould lengths. Where $s$ is smaller $W_s$ lies correspondingly lower and $q_s$ may rise to 25,000–30,000 kcal/m$^2$.

### Solidification Processes on Slab Sections

Extensive investigations were carried out at Kapfenberg on solidification processes in continuous casting. The experiments were mainly carried out on slabs by one of three processes.

In the first method the strand is opened up near where the molten core tapers off, and the molten metal is allowed to flow out. After cooling, longitudinal and cross-sections are prepared. This process is a reliable means of showing the growth of the shell for the upper half of the liquid core. In the case of larger sections, however, this process is inconvenient and expensive.

In the second method a radioactive phosphorus or sulphur isotope is added to the liquid steel. After solidification, sections are again prepared and radiographs produced.[12] They give information regarding segregation of the sulphur or phosphorus. The parts which were solidified before the radioactive isotopes were added do not radiate and therefore do not affect the film. As shown in Fig. 2, the line of demarcation between the solidified and the fluid metal can be seen very clearly. This process also shows that there is a strong convection current in the liquid metal, which leads to the radioactive isotopes being distributed very rapidly throughout the molten metal. The consequence of this strong current in that the temperature of the liquid metal, ignoring any possible superheating of the metal added, must be about the same level everywhere and almost at the liquidus temperature. To throw some light on this problem measurements of the temperature of the metal were made in the casting stream and in the mould on flat sections with thicknesses of 110, 170, and 230 mm, by means of immersion elements. The results are shown in Table II, and confirm the conclusions drawn from the radiographs. Schaaber[13] has also dealt with the question of convection currents in solidification. The strong current means that the excess heat is not only transferred to the mould where the crust is thin, but over the whole of the internal surface over which the current passes. Since heat transfer from the internal surface is markedly reduced as the thickness of crust increases, excess heat in the melt means that in large sections the solidification rate is also adversely affected outside the mould, in the secondary cooling stretch. Superheating not only leads to a reduction in the casting rate, but also to the length of liquid metal in the strand being increased, which may cause internal faults. The end of the liquid core cannot be detected when this process is used, since the radioactive isotopes are not carried into the bottom of the

**Table II**
**TEMPERATURES IN CASTING STREAM AND MOULD**

| Type of Steel | Section, mm | Temperature, °C | |
|---|---|---|---|
| | | Casting Stream | Mould |
| CK 10 | 370 × 170 | 1605<br>1610<br>1600 | 1530<br>1530<br>1530 |
| C 85 WS | 500 × 110 | 1530<br>1540<br>1550 | 1465<br>1470<br>1470 |
| Ni–Cr steel<br>0·10% C<br>0·70% Cr<br>2·50% Ni | 360 × 230 | 1620<br>1630<br>1620<br>1625 | 1540<br>1540<br>1540<br>1540 |
| CK 45 | 370 × 170 | 1570 | 1500 |

liquid pool by convection currents. When the width of the liquid core is about 20 mm the current is reduced, ceasing altogether when it reaches 10–15 mm (*see* Fig. 3).

The third method is the addition of lead to the liquid core as described by Bojtschenko.[14] The liquid lead penetrates to the end of the core. This is shown either by means of radiographs or by the use of sections, usually after a preliminary radiographic examination.

Evaluation of a large number of experiments showed that the growth of the crust comes very close to following a quadratic parabola, as was noted by various observers, for example, Klein,[15] Roth,[16] and Savage.[17] The cooling conditions in the secondary cooling stretch naturally have a considerable effect on the solidification processes. On the basis of average cooling conditions, and casting temperatures of 70–90° C above liquidus, the characteristic quantity $K_1$ shown in Fig. 4 is obtained. The figure gives the rate of casting which, under the usual conditions at Kapfenberg, leads to a liquid core depth of 1 m in slabs. If, for example, a slab 150 mm thick with a casting rate of 0·6 m/min is to be produced a liquid core depth of 5 m will result. In addition to the total depth of the liquid core, however, the formation of the end of the core, which is that part of the liquid core practically free from convection currents, is also of great importance. The smaller the angle of the point of the liquid core, the greater the tendency for internal flaws to occur. To measure this angle the point of the liquid core is assumed to be an isosceles triangle. This has a base of 20 mm and its height, in relation to the total depth of liquid core is given as $K_2$ in Fig. 6.

The angle of the opening $\alpha$ is given by:

$$\alpha = \frac{1 \cdot 15\ K_1}{vK_2} = \frac{K_2}{v} \text{ when } K_2 = \frac{1 \cdot 15\ K_1}{K_2} \quad \ldots\ldots\ldots(7)$$

In the case of slabs and killed steels $\alpha$ may be chosen as 0·5–1·0 according to the type of steel. In the case of steels which show a particular tendency to segregate, such as ledeburitic steels, it will be considerably higher; in steels where the requirements as regards internal faults such as pipes in the strand are not so high, it will be somewhat lower. This agrees with ingot-casting experience. A high $\alpha$ means

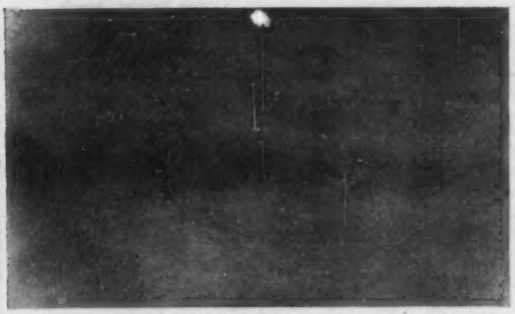


**Fig. 3—Longitudinal radiograph of apex of cone of solidification in slab with $^{32}P$ added**

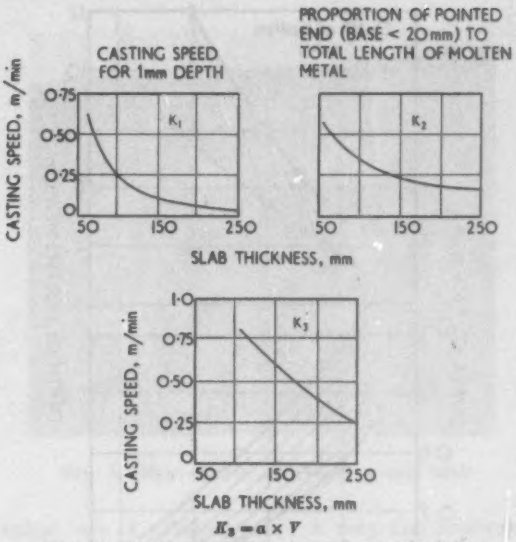



**Fig. 4—Depth of molten core in steel slabs**

a low rate of casting and small cross-section at low casting temperature, which are also employed for high-speed and ledeburitic steels.

### Layout of a Continuous-casting Steel Plant

In planning a continuous-casting plant a compromise must be made, and adjustments made to fit requirements from metallurgical, casting technique, and economic viewpoints. For average demands and casting conditions a table showing the rates of casting for slabs and the heights of liquid core has been drawn up (Fig. 5). This does not cover extreme conditions. In special cases it may well be that higher or lower rates of casting might be suitable. It will be clear from the diagram that the height of the plant, which is influenced to a large extent by the depth of the liquid core, increases rapidly as the slab thickness increases, whereas the casting rate drops, so that, with the same slab width, there is practically no increase in casting capacity over about 150-mm slab thickness; in certain circumstances it may even fall, if it is impossible to provide the necessary height in the structure. Table III shows quite clearly that with the same cross-sectional area the narrower cross-section, which also has a larger $u/f$ ratio, is superior.

The casting capacities limit the maximum size of slabs. For this reason attention was very soon given at Kapfenberg to multi-strand casting, and the first multi-strand continuous-casting plant for steel was operated there. Up to four strands have been cast successfully. The experience gained in this plant suggests that the use of 8-fold distributors is possible. Since the problem of multi-strand casting has been solved there is no longer any purpose in attempting to obtain higher casting capacities by means of increased rates of casting.

The required number of strands can be calculated with the help of Fig. 5 and Fig. 6, which give the most suitable casting times for stoppered ladles with covers, which are highly pre-heated. In multi-strand

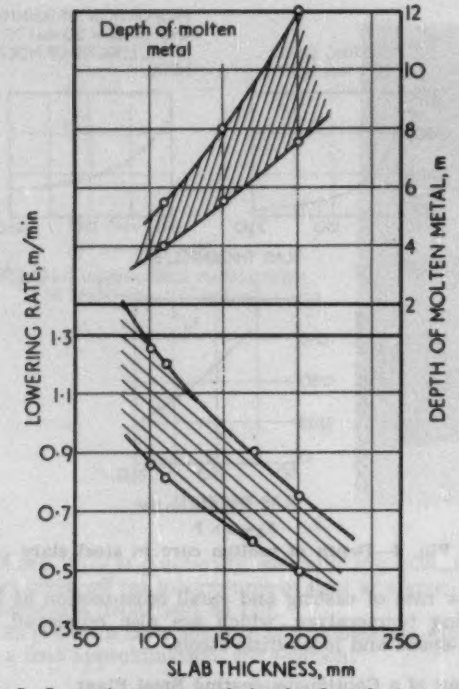



**Fig. 5—Lowering rate and depth of molten metal in continuous casting**

casting plants it is advisable to make provision for an extra strand, in addition to those given in the calculation, to be kept in reserve should trouble occur. Generally, the slab section chosen should be no larger than is strictly necessary, since the time required for cutting slabs must be taken into consideration. Under certain circumstances, when dealing with wide slabs, the length to which they are cut is twice the width, even when two burners are used, which means that there must be a further increase in plant height.

Autogenous cutting of stainless steels is now functioning quite satisfactorily, after the initial experimental period, but when costing, attention should be paid to powder cutting and to the material losses involved in cutting.

In cutting unalloyed or low-alloy steels it was found that at temperatures of 600–900° C the cutting speed is 50–100% higher than with cold slabs. As a general rule the rate of feed was 400 mm/min for the 110-mm thick slabs, 320 mm/min for the 170-mm slabs, and 180 mm/min for the 230-mm slabs. With the help of these figures it is a simple matter to work out the shortest cut lengths which are possible at given rates of casting.

### Difficulties Encountered

Special attention must be paid to the cooling of the strand when it has left the mould, since errors in the secondary cooling stretch are often the cause of material being rejected. In the thinner sections abrupt cooling in the secondary cooling stretch leads to an increase in the rate of casting. In the case of thicker sections the rate of solidification is so much dependent on the thermal conductivity of the crust of the strand that the cooling in the secondary cooling stretch exerts less influence on the rate of casting. Many steels, however, cannot stand very abrupt cooling in the secondary cooling stretch and the high rate of casting which this entails in the smaller sections. If cooling in the secondary cooling stretch is too slow and uneven, however, there is an increased tendency to internal faults such as pipes, especially at higher rates of casting.

### Cracks

Figure 7 shows internal cracks in the narrow side of a 230-mm thick slab. Five different kinds of crack have been observed.

*Cracks due to uneven thickness of the crust in the mould*—These cracks occur mainly when round moulds are used for casting. For example, the strand may be in contact with the mould in only three places, where the crust is considerably thicker. The shrinkage caused by the increased cooling at these points then leads to bend stresses occurring at points lying in between, and this results in cracks, since many steels will not stand deformation at temperatures near the solidification point. The occurrence of these flaws is favoured by the mould being too long, by the temperature on the internal wall of the mould being too low, and by superheating of the metal.

*Cracks due to re-heating of the surface*—Re-heating of the surface may occur both in the mould and in the secondary cooling stretch. In the mould it is caused by the strand leaving the wall of the mould. If this takes place unevenly, the cooling effect in the mould may be so diminished that re-heating occurs in the outer layers of the crust. Dangerously wide separations also occur in the large sections, if uniform contact between strand and mould is not ensured by the conicity of the mould. For purposes of illustration it may be mentioned that with a mould breadth of 1 m and 100° C cooling a shrinkage of 2 mm is to be reckoned with in the austenitic range. Reheating of the outer layers of the strand causes these to expand; tensile stresses then occur in the layers lying below the surface which have just solidified, resulting in heat cracks. In addition, if the separation is too

**Table III**
**CONTINUOUS SLAB CASTING CAPACITY**

| Section | Weight, kg/m | Range of Casting Capacity per Strand, tons/h | |
|---|---|---|---|
| | | Minimum | Maximum |
| 100 × 400 | 310 | 16 | 22·6 |
| × 500 | 390 | 20 | 28·6 |
| × 750 | 585 | 30 | 42·9 |
| 120 × 480 | 450 | 21 | 30 |
| × 600 | 560 | 26·2 | 37·5 |
| × 900 | 840 | 39·3 | 56·3 |
| 150 × 600 | 700 | 29·3 | 42 |
| × 750 | 880 | 37 | 52·8 |
| × 1150 | 1320 | 55·5 | 79·2 |
| 170 × 680 | 900 | 32·4 | 48·6 |
| × 850 | 1120 | 41·0 | 60·5 |
| × 1315 | 1680 | 61·5 | 90·8 |
| 200 × 800 | 1250 | 37·5 | 56·2 |
| × 1000 | 1560 | 47 | 70 |
| × 1500 | 2340 | 70·5 | 105 |

large and the crust too thin, ferrostatic pressure may cause cracks to appear in the crust either in the mould or immediately below it. This can be avoided by the use of conical moulds.

The same type of crack may also occur in the secondary cooling stretch, especially if the cooling there is irregular. It was frequently observed that abrupt cooling, if it is really uniform, is less dangerous than irregular cooling where surface re-heating occurs.

*Cracks due to too high a rate of casting*—Steels with a high $\gamma \rightarrow \alpha$ transformation point and a high rate of transformation in the pearlitic stage may suffer internal cracking if the rate of casting is too high, as was shown by observations on very low-carbon pure iron.

*Cracks due to mechanical causes*—Internal cracks also occur if the strands are subjected to high mechanical pressure, e.g. by the lowering rolls, before they are fully solidified and have cooled below the critical temperature.

*Cracks due to ferrostatic pressure*—With large sections and high rates of casting (great depth of liquid metal) the strand may bulge as a result of ferrostatic pressure, which again may be the cause of cracks. This trouble can be avoided by the use of a supporting roller arrangement in the secondary-cooling stretch. This keeps the faces of the strand flat.

**Effect of Casting Temperature**

The adverse effect of too high a casting temperature has often been pointed out. Systematic investigations on a 500 mm × 110 mm slab showed that a 40° C increase in the casting temperature increases the depth of liquid metal by 1 m when the rate of lowering is the same, or, as determined by Speith and Bungeroth,[18] the rate of casting has to be reduced by 20–25% to give the same depth of liquid metal. A casting temperature which is too high has a more marked effect in the case of thick sections than in the case of thin ones. The increase in the length of liquid metal again favours the occurrence of internal flaws. Every effort should therefore be made to keep the casting temperature as near as possible to the liquidus temperature.

**Structure of Slabs**

The size of the ledeburite network formed during solidification of high-speed steel in continuous casting in a small mould is very closely connected with the radial rate of solidification. A very fine ledeburite network is thus possible only in relatively small dimensions of strand, which must, in addition, be cast at lower speed to avoid internal flaws.

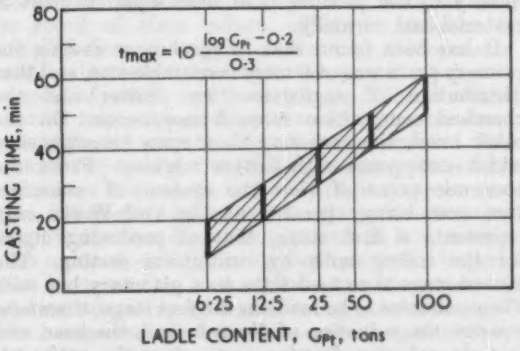



**Fig. 6—Recommended casting time for steel from stoppered and covered ladle**

**Fig. 7—Heat-stress cracks in a cast slab**

**Magnetic Fields**

Very extensive systematic investigations were carried out on the effect of magnetic fields on solidification. In almost all cases the use of special fields brought an improvement in the surface and in many cases there was a reduction in the number of internal flaws. Occasionally, however, conglomerations of non-metallic inclusions were observed.

## References

1. H. Bleckmann: *Stahl Eisen*, 1934, vol. 54, pp. 1177–1180.
2. H. Krainer and B. Tarmann: *Ibid.*, 1949, vol. 69, pp. 813–819.
3. H. Krainer and B. Tarmann: *Ibid.*, 1950, vol. 70, pp. 1098–1108.
4. W. Schwarzmeier: Detailed summary of patent literature in "Continuous Casting," 1957, Stuttgart, Berliner Union.
5. J. Hoffmaier: *Stahl Eisen*, 1957, vol. 77, pp. 69–78.
6. F. Leitner: *Iron Coal Trades Rev.*, 1955, vol. 171, pp. 1241–1244.
7. Austrian Pat. No. 175352, Gebr. Böhler and Co. A.G. Vienna.
8. Austrian Pat. No. 179208, Gebr. Böhler and Co. A.G. Vienna.
9. Austrian Pat. No. 174448, Gebr. Böhler and Co. A.G. Vienna.
10. German Pat. No. 750301, S. Junghans.
11. Austrian Pat. No. 173807, Gebr. Böhler and Co. A.G. Vienna.
12. H. Krainer and E. Krainer: *Atompraxis*, 1957, vol. 12, pp. 453–458.
13. O. Schaaber: *Z. Metallk.*, 1952, vol. 43, pp. 181–190.
14. M. S. Bojtschenko: "Continuous Casting of Steel," 1957, Moscow.
15. N. Klein: *Giess. Tech. Wiss.*, 1952.
16. W. Roth: *Z. Metallk.*, 1940, vol. 32, pp. 10–14. *Ibid.*, 1949, vol. 40, pp. 445–460.
17. J. Savage and W. H. Pritchard: *J.I.S.I.*, 1954, vol. 178, pp. 269–277.
18. K. Speith and A. Bungeroth: *Stahl Eisen*, 1952, vol. 72, pp. 869–885.
19. K. Speith and A. Bungeroth: *Ibid.*, 1956, vol. 76, pp. 437–442.

# Continuous Casting of Steel in France

*By P. Thomas*

SYNOPSIS

**The paper surveys continuous casting in France at the three existing plants. The Jacob Holzer plant at Unieux, the oldest, aims at the production of small spring-steel billets (6–12 in²) at low speeds. At each operation 1½ tons of billets are cast.**

**At the Ets. Cail at Denain the output is of ordinary and special grades of steel, in billets of 90 in² section at low speeds, but at high total rates (35–60 tons/h). The grades cast include extra-mild killed or unkilled steels, semi-hard and hard carbon steels, Cr–Ni–Mo steels, and silicon steels for magnetic sheet.**

**The third plant, at Allevard, produces billets of ordinary and special grades of steel at 10–20 ft/min and 10–12 tons/h; the sizes are from 8 to 17 in² section.** 1618

THERE ARE three continuous casting plants in existence in France. All three differ very little in principle. However, each has had a slightly different objective in view.

The oldest of these works, that of Jacob Holtzer at Unieux (Loire), aims at the direct production of small billets (6–12 in²) of special steels, at low speeds.

The second works to go into industrial production, Établissements Cail of Denain (Nord), has the largest production to date—85,000 tons by the end of October, 1957; their aim, in the first stage at least, is to produce large billets of standard and special steel (of the order of 90 in²) at low speeds (about 2 ft/min) but at high total rates (35–60 tons/h).

The third plant, put into operation at Allevard (Isère) at the beginning of 1956, aims at producing, at high speeds (10–20 ft/min) and medium output (10–12 tons/h), billets of standard or alloy steels (especially spring steel) in small sizes of 8–17 in².

### Jacob Holtzer Plant, Unieux

The casting machine is of the vertical type. It has a height of about 33 ft (13 ft above and 20 ft below ground. The h.f. furnace is sited above the mould. The metal is cast direct into the mould through a casting tundish with one or two nozzles according to the number of strands being cast. One mould is used in the case of the 80 × 105 mm (3 × 4 in.) billet, and two for the 60 × 80 mm (2½ × 3 in.) billet, the section being an oval.

The copper mould, which is water-cooled, is 28 in. high. In view of the low rate of casting in relation to the section of the product, secondary cooling after the mould is unnecessary. The billet is carried away by a double train of rolls with variable pressure at a speed of 1½–2 ft/min.

In general 1½ tons of billets are cast in one operation; these are cut into lengths by hydraulic shears. The billets are sound; their surface is a little rough owing to the slow casting speed, but they offer no difficulty in rolling. Owing to its rather low output this method is applied more particularly to expensive steels, where impeccable quality is the first consideration.

### Ets. Cail Plant, Denain

This plant was constructed in accordance with the designs of Dr. Junghans, but was put into operation by the engineers at Cail. It started up in January, 1955, and came into full industrial operation in August, 1955. This machine is also of the vertical type, permitting a 35-ton ladle to be cast in about 45 min. The ladle is of the standard type and tilted mechanically; it is strongly heated before casting. The metal is cast into four moulds of 240 × 240 mm by 1 m high (10 × 10 in. by 3¼ ft) through a main channel and two secondary channels. The metal is distributed to the moulds, flowing into one mould or another by varying the tilting of the channels.

The mould, which is made from heavy copper in several sections, is water-cooled and is given a reciprocating movement to facilitate the passage of the billet and prevent rupture of the skin. The mould is not lubricated.

Cooling of the billets is completed by spraying from four atomizer rings placed below the mould, and then by passage through a sleeve, the walls of which are water-cooled.

Movement of the billets is regulated by a group of rolls which ensure that the speed of descent is practically constant; this may vary between 1½ and 2 ft/min. The billets are then flame-cut.

Various types of steel have been cast: extra-mild killed or unkilled steels, semi-hard and hard carbon steels, Ni–Cr–Mo alloy steels, and in particular silicon steels for magnetic sheet. Generally speaking, the quality of the product is at least equal to that of material cast normally.

It has been found that in continuous casting the primary grain was of a more favourable size, and that distribution of segregates was better and the chemical composition more homogeneous. On the other hand, the core may show some heterogeneity, which disappears with further working. From the economic point of view the system of manufacture now being operated at the Cail Works only represents a first stage, that of producing ingots for the rolling mills by continuous casting. The second stage is to feed slabs to a planetary hot mill. The economies to be made in the first stage, therefore, concern the reduction of discards from the head and foot, in reducing dressing costs, since the surface is good, and in improvement in the yield from the

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This is a slightly abridged version of the paper presented at the 10th Technical Session in Charleroi of the Journées Internationales de Sidérurgie.

Monsieur Thomas is General Manager of the Société des Hauts Fourneaux et Forges d'Allevard.

rolling mill, since bad ends due to the ingot are no longer produced. For the rest, the costs inherent in continuous casting are of the same order as those for ordinary casting.

The use of continuous casting thus represents a substantial economy; this will be considerably increased in the second stage when slabs are produced that can pass directly to a finishing mill.

### Allevard Plant

This plant was built in 1955; the first casts were made in December, 1955, and the machine has been in industrial operation since 1957.

The continuous casting apparatus was constructed according to the Rossi design, by the Allevard engineering staff. It is also of the vertical type; a 12-ton ladle is cast in 50–70 min, according to the section of the billet.

Owing to the presence of water, the apparatus was built entirely above ground and is about 65 ft high. The ladle, which is of the standard type, is heated by a burner before and during casting. It is tipped by a hydraulic device, controlled either by hand or automatically. The metal is poured over the lip into a heated tundish. An automatic system based on the height of metal in this tundish regulates the flow of metal from the ladle.

The tundish pours the metal through a zircon nozzle into the mould, consisting of a water-cooled copper tube. It is about 2 ft high and is reciprocated with a 3–4-cm stroke.

At the present time two ingot mould sections are being used industrially, one 75 × 75 mm (3 × 3 in.) and the other 140 × 90 mm (5½ × 3 in.). The billet passes through the mould at about 8–13 ft/min. The mould is lubricated with colza oil.

The temperature of the metal is measured twice: when it is poured into the ladle from the 10–12-ton furnace which feeds the plant, and in the ladle itself. Temperatures are taken with a Land pyrometer.

On emerging from the mould the billet enters a girdle of rollers, which grip it alternately on different faces. It is sprayed by atomizers between each pair of rollers. There are also 14 ranges of atomizers, which can be regulated individually to obtain a cooling effect most likely to give homogeneous solidification.

The billet is drawn by two pairs of rolls grooved according to its dimensions, the axes being at 90°. The speed of these rollers, which is variable, is controlled from the upper platform by the operator watching the level of metal in the mould. Owing to the speed of casting and the small size of the mould, it is almost impossible to keep the metal at a constant level without varying the delivery speed. The automatic system for regulating delivery from the ladle allows delivery to be kept within quite narrow limits, but there must be additional speed regulation. Except in the case of accident, variations in speed are of the order of ± 10% during any operation. Experiments have recently been carried out with a view to replacing manual speed regulation by automatic regulation using a radio-cobalt source and a Geiger counter.

The billet is then flame-cut to the length required by the rolling mills and is placed in the coolers.

In view of the results obtained at Barrow in bending 2-in. billets, experiments were carried out with the sizes used at Allevard. It has been decided that on the new machine to be installed the billet will be bent to horizontal and cut by shears. This will avoid flame-cutting, which causes some trouble in the mill. The speeds at Allevard are 10–15 ft/min for the 75 mm (3-in.) and 6½–10 ft/min for the 145 × 90 mm (6 × 3½ in.) billet, which produce 10–12 tons/h.

Contrary to certain opinions, Allevard have found that high speeds do not cause defects in the sizes tested. On the contrary, central heterogeneity is always very slight and disappears altogether after four or five workings. The mechanical properties of bars produced by continuous castings are always at least equal to those produced by classic methods of casting. The surface finish is superior to that obtained at low speeds. Allevard have never carried out any cleaning or grinding work on this material.

The most important defects to be avoided in continuous casting of small billets is cracking at the corners of the section, which happens when the billet loses its squared shape and becomes lozenge-shaped. The crack may be either internal or external.

The main causes of this defect are, firstly, defective regulation of secondary cooling after the mould, as regards both position and delivery, which can be eliminated with experience, and defective mould shape. The shape of the mould must be examined with the greatest of care. The dimension of the radii of curvature between the plane faces is of great importance. With wear, which varies according to the amount of heating during casting, the mould loses its shape, and must be machined to bring it back to correct shape.

The frequency of cracking varies with the quality of steel. Cracks are rare in semi-mild, semi-hard, or hard carbon steels. Silicon–manganese spring steel appears to be one of the most susceptible, more so than Cr–Mn steels or even stainless Cr steels for cutlery, where the casting tests have been very encouraging.

With a teapot ladle there is hardly ever any slag, since in this system contact with air is very short.

It is thought preferable at Allevard to increase casting speeds rather than to provide multiple strands, except when there are two identical equipments fed by the same casting ladle. Allevard are to erect a second machine, incorporating all the results of two years' experience with the first, which will later be modified. Once these two plants have been erected, the existing blooming mills will be dispensed with.

It is anticipated that 98% success will be achieved with the final plant. During the last few months Allevard have recorded 90–95% success with an average of 4–5% rejects on silicon–manganese steel, despite the very high standard set.

From the economic point of view Allevard have confirmed an economy of 8–10% on the billet cost. They are counting on a saving of at least 15% with the final plant and when they have a properly trained staff. All difficulties have not yet been eliminated; in view of the results obtained however, success is assured. For steelworks of modest size whose production does not warrant a modern blooming mill, this is an economical and reliable process.

# The Effect of Alloying Elements on Creep Behaviour

*By J. Glen, B.Sc., A.R.C.S.T., F.I.M.*

SYNOPSIS

Evidence is presented to show that, unlike pure metal or simple solid solutions, the creep resistance of most alloys depends on various strain-age-hardening or strain-induced precipitation phenomena. Each of these effects results in what has been termed a transition in creep rate, i.e. a sudden deceleration in creep rate over an interval of time.

A simple theory has been developed to explain these transitions in creep rate and to show the effect of the stress and temperature of testing. Proof of this theory is given by the results of many creep tests on steel. The effects of N, C, Mn, Cr, Mo, V, Ti, and Si as alloying elements are considered in some detail. The results of creep tests on austenitic alloys and Ti alloys are also given to show that transitions in creep rate are of common occurrence in most commercial alloys. 1599

AS LONG AGO AS 1935 Bailey[1] demonstrated the effect of what he called 'thermal hardening.' Some ten years later the author stated[2] "It is surprising that, apart from Bailey, no one appears to have realized the significance of this thermal hardening, an understanding of which, in the opinion of the author, provides the key to further development of creep-resistant alloys." Since that time the author has carried out further investigation of this problem and has now concluded that thermal hardening can be more simply described as a form of strain-age hardening or strain-induced precipitation hardening, since strain is just as important as temperature.

The influence of strain-age hardening on the results of high-temperature tensile tests has already been reported.[3, 4] The present paper puts forward a simple theory which helps to explain the effect of strain-age hardening and other phenomena on the creep behaviour of industrial alloys. A simple statement of the basic concept of this new theory has already been given.[5] It was shown that, unlike pure metals, one or more transitions in creep rate occur in the creep curves of several steels. These transitions take the form of a sudden deceleration in creep rate over an interval of time and can occur at any stage in a creep test. To show up these transitions in creep rate in their true perspective the creep data were presented in the form of log total plastic strain/log creep rate curves (strain/rate curves). The method of obtaining such curves was described. It was also shown that families of strain/rate curves, either at constant stress or at constant temperature, form a simple pattern so that it is possible to estimate the shape and position of strain/rate curves for lower temperature or stresses. These curves are easily integrated to give the ordinary strain/time creep curves. Thus, extrapolation of the results of creep and rupture tests to long testing times can be carried out with some theoretical justification.

In the previous paper,[5] the main emphasis was on extrapolation of creep data, since this is perhaps the most important practical problem at the present time. To facilitate the development of new alloys, however, it is important to understand the metallurgical changes which take place during creep testing, and in particular to determine the effect of alloying elements on such changes. The stress and temperature of testing are also important because they influence the rate at which metallurgical changes take place. Furthermore, the initial condition of the samples must also be considered as this varies with the thermal history and heat-treatment given to the material, and also on such factors as warm work or cold work. Because so many variables are involved it is extremely difficult to interpret the results of creep tests. However, as is shown below, the use of strain/rate curves eliminates many of the problems of interpretation.

To simplify the presentation of the data in this paper a brief summary of the background knowledge is given, followed by an outline of the theory. Finally, experimental evidence is presented for a variety of steels and other alloys to illustrate the various phenomena and also to indicate the effect of various alloying elements.

## BACKGROUND KNOWLEDGE

### Simple Metals

It is obviously difficult, if not impossible, to attempt a solution of the creep behaviour of a complex alloy without at least having some idea of the basic creep law for a pure metal. Many equations have been suggested, based on limited experimental evidence, but all have failed to withstand more rigorous testing. Dorn *et al.*[6] did not attempt to obtain an equation to fit the shape of a creep curve but put forward a correlation between strain and time which considerably clarifies the problem. From X-ray analysis and plastic properties they concluded that the same submicroscopic structure is developed at the same value of $te^{-\Delta H/RT}$ following creep at the same stress (where $t$ = time, $T$ = absolute temperature, and $\Delta H$ = activation energy). The above function was called temperature-compensated time.

At high temperatures of testing, i.e. where rapid crystal recovery can occur, the activation energy for creep ($\Delta H$) approximates to that for self-diffusion of the particular metal being tested. At lower temperatures the activation energy for creep is also found to be constant,[7] but in this case it is considerably smaller than the activation energy for self-diffusion.

The above relationship presupposes a thermally stable material. If grain growth occurs during testing,

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as was noted by Guard and Hibberd,[8] or recrystallization such as was found in tests on pure Pb by Greenwood,[9] then obviously the relationship no longer holds. However, in commercial alloys such effects seldom occur so that the above complications need not be further discussed.

In Fig. 1 are shown diagrammatic creep curves for a pure metal at constant stress and various temperatures. If the time scale were to be replaced by temperature-compensated time all the curves would coincide. Thus, in the appropriate range of temperature, if two or more creep tests are carried out at constant stress it is a simple matter to calculate the activation energy. Knowing the activation energy, it is then easy to calculate the creep curve at the same stress for any other temperature. Using this method of analysis, it is not necessary to know the actual equation of the creep curve, which in any case might be different for each material and in each condition tested. Another important conclusion from Dorn's work is also illustrated in Fig. 1. As will be noted, the end of primary creep and the onset of tertiary creep occur at identical strain values, no matter the temperature of testing.

In a pure metal the only structural change which can take place during creep testing is strain hardening, or rather the multiplication of dislocations. Thus, the pure metal can be considered to have a certain initial creep resistance which does not alter during testing. Thus the initial creep resistance comprises the total creep resistance.

The addition of an element which goes into true substitutional solid solution increases the strength properties because of lattice distortion. The degree of distortion depends on the difference in atomic radius between solute and solvent. The addition of solute atoms also increases the strength at high temperature by increasing the recovery and recrystallization temperature. The initial creep resistance of a solid solution is thus greater than that of the pure solvent metal, but it is not to be expected that the creep behaviour is otherwise different. Thus, the method of analysis proposed by Dorn for a pure metal also applies to a simple solid solution as, indeed, he has shown.[10]

It is, of course, well known that the presence of a precipitate in fine (or coherent) dispersion increases the strength properties at ordinary temperatures and that even a coarse dispersion can have a considerable effect, as has been clearly shown by Gensamer for steel.[11] Thus the presence of a precipitate will increase the initial creep resistance. With a very fine dispersion it is to be expected that the initial creep resistance will be much greater than that of a pure metal or even of a simple solid solution. If the testing temperature is low enough, the rate of spheroidization of the precipitate will be so small that the precipitate will remain virtually unaffected during the progress of the creep tests. It might be expected therefore that in this case also the method of analysis proposed by Dorn for a pure metal will also apply. Giedt *et al.*[12] have investigated the creep properties of a thermally stable alloy containing such a precipitate and have found the activation energy to be the same as that of the pure metal, thus proving the above contention.

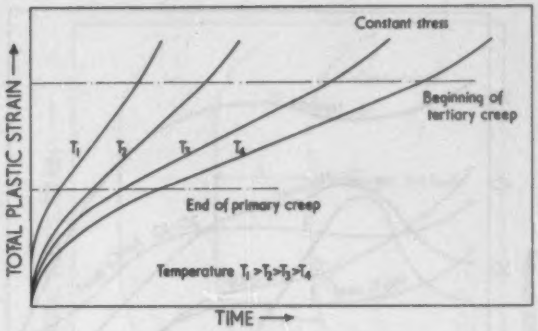


**Fig. 1—Ideal creep curves for a pure metal**

In the above three cases there is evidence to believe that creep at constant stress can be correlated by a simple functional relationship. This might have been expected, since in all these cases the only structural change in the material during creep is that resulting from strain hardening. This increases during primary creep and becomes constant during secondary creep. It is perhaps more correct to say that the removal and replenishment of dislocations become equal in the secondary creep stage.

Unfortunately, in most, if not all, cases involving practical materials the creep curves do not obey a simple functional relationship of the above type. As evidence of this it suffices to state that such materials, when tested at constant stress, do not reach the end of primary creep or the beginning of tertiary creep at the same strain values over a range of testing temperatures.

It can be concluded, therefore, that changes in structure occur during the creep testing of most alloys which are more complex than that resulting from simple strain hardening. It is essential, therefore, to know most of the effects of alloying elements and to determine, if possible, which are of major importance. Rotherham and Tottle[13] have reviewed this subject and detailed many of the possible effects of alloying elements so that there is no need to detail them here. A few effects must, however, be mentioned since they are of fundamental importance as regards the paper. They are discussed below.

### Strain-age Hardening

When a metal is deformed plastically, multiplication of dislocations takes place and the metal is hardened because of mutual interference between these dislocations. This simple form of hardening, which has been called strain hardening, is the only method of hardening pure metals. If steel is deformed at room temperature it is strain hardened, but after a considerable time at room temperature, or a short time at a higher temperature, further hardening takes place. This has been termed strain-age hardening or strain ageing. By deforming plastically at temperatures above room temperature, strain-age hardening can take place during the process of straining.

The author has already shown[4] that strain-age hardening at high temperatures is a complex phenomenon. By carrying out short-duration tensile tests

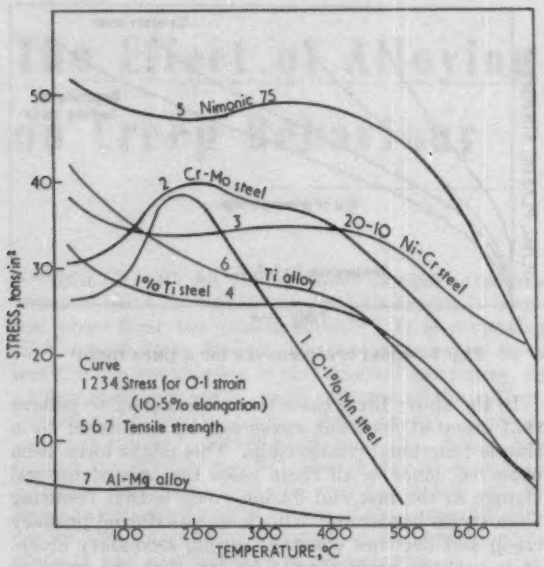


**Fig. 2—High-temperature tensile properties of various alloys**

at various temperatures on a simple Fe–C alloy it was found that a maximum in stress occurred at about 200° C. At this temperature, therefore, strain-age hardening was a maximum under the conditions of test used. At a lower temperature less than the maximum strain ageing is obtained, whereas at a temperature higher than 200° C over-ageing or recovery takes place. The author has suggested that the increased strength results from some form of coherent precipitation of carbide and nitride in the dislocations formed during straining rather than by the formation of 'atmospheres' as postulated by Cottrell.[14]

With the addition of a carbide-forming element, such as Mn, Cr, etc., a second maximum in strength is obtained at a temperature higher than 200° C. In these cases the second strain-age-hardening effect appears to be associated with the precipitation of a particular alloy carbide in the dislocations during straining.

Strain-age hardening is obviously taking place when a maximum is obtained in tensile strength, as is the case, e.g. with mild steel at about 200° C, but the absence of a true maximum in stress does not mean that strain-age hardening is absent. A retardation in the normal decrease in strength with increasing temperature is a sufficient indication of this phenomenon. Figure 2 shows typical examples of stress/temperature curves for various materials from which it can be concluded that strain-age hardening at high temperature is quite a common occurrence, even for austenitic steel and non-ferrous metals.

During creep testing a test-piece is strain hardened to a greater or less extent depending on the stress and temperature of testing. It is to be expected, therefore, that one or more strain-age-hardening effects may operate to increase the creep resistance while the test is in progress. Strain-age hardening, however, cannot begin until some strain hardening has taken place. Thus, strain-age hardening has no effect initially so that it does not influence the initial creep resistance. Any strengthening effect of strain-age hardening during testing is additive to the initial creep resistance so that in such cases the total creep resistance is compounded of two parts, the initial creep resistance and what may be called the latent creep resistance.

One other aspect of strain-age hardening has been noted which appears to be of fundamental importance in relation to creep testing. From the tensile tests carried out on simple Fe–C alloys with alloy additions[3, 4] it was found that a powerful carbide-former modifies the effect of a less powerful one. For example, at 200° C chromium carbide cannot precipitate since Cr atoms diffuse too slowly at that temperature. The addition of Cr, however, reduces the intensity of hardening at about 200° C and shifts the temperature at which maximum ageing occurs to a somewhat higher temperature. It would appear that the carbon and nitrogen atoms in interstitial solution tend to segregate to interstices adjacent to Cr atoms, and thus have difficulty in migrating into the dislocations formed during straining. Such effects appear quite common and thus it is to be expected that the intensity of each strain-age-hardening effect which may operate during creep testing will alter depending on the amount of each alloying element present. This phenomenon makes it difficult to assess the relative importance of solution hardening in such alloys since what is thought to be solution hardening may, in some cases, simply be the effect of one alloying element on the strain-age-hardening behaviour of another alloying element.

### Precipitation Hardening

Although much has been written about precipitation hardening, comparatively little is known about its effect on high-temperature mechanical properties. In the solution-treated condition the 'yield stress' of a precipitation-hardening alloy is low, so that in a creep test, even at a low stress, the creep rate in the initial stages of testing is high, i.e. the initial creep resistance is low. In the precipitation-hardened condition the 'yield stress' is high, so that the creep rate in the initial stages is low. Even in the over-aged condition this may still apply since the yield stress is usually higher than that of the solution-treated condition. In both cases the initial creep resistance is higher than that of a solution-treated sample.

In longer-duration creep tests, however, a simple relationship between yield stress and creep resistance, such as is indicated above, cannot apply, since structural changes occur during the progress of a creep test, which may result in an increase or decrease in the creep rate. For example, in creep testing at a temperature near the ageing temperature, a precipitation-hardened sample, although initially good, will over-age rapidly and fail quickly. The solution-treated test piece, however, will harden before it over-ages, so that failure will be delayed.

As already indicated, strain-age hardening manifests itself when excess dislocations are present. Strain-

induced precipitation can, however, also occur with precipitation-hardening alloys. Indeed, as shown by the author,[3, 4] there is little or no difference between the two types of alloy in high-temperature tensile tests. This is illustrated in Fig. 3 for two Mo steels in the normalized, and normalized and tempered conditions. It will be noted that the 1·5%Mo steel is definitely of the precipitation-hardening type, since the tempered test-piece is harder at room temperature than the normalized one, but that in both conditions it shows a strain-age-hardening effect at about 500° C similar to that of the lower-molybdenum steel. It can be tentatively concluded, therefore, that during tests such as high-temperature tensile or creep tests, precipitation-hardening alloys will behave in a similar manner to strain-age-hardening alloys.

**Tempering (or Ageing) and Spheroidization**

Because of the similarity of behaviour of strain-age-hardening alloys and precipitation-hardening alloys, the effect of tempering before creep testing is more easily discussed. When an ordinary alloy steel is normalized, the equilibrium amount of alloy carbide has not time to form, but iron-rich carbide forms. Thus, the initial creep resistance of such alloys is reasonably high and the latent creep resistance is also high. By tempering, alloy carbide can be formed in a fine dispersion, so that the initial creep resistance is increased. However, since alloying element has been removed from solution, less remains to precipitate in the dislocations during testing. Thus, although tempering can increase the initial creep resistance, it decreases the latent creep resistance. With more prolonged tempering considerable spheroidization of the carbide can occur, so that the initial creep resistance may be reduced; at the same time the latent creep resistance tends to reach a minimum value.

In alloys which can be solution treated to give a one-phase structure, the initial creep resistance will be quite low, but the latent creep resistance may be very high. Tempering of such steels may greatly increase the initial creep resistance, again, of course, at the expense of latent creep resistance.

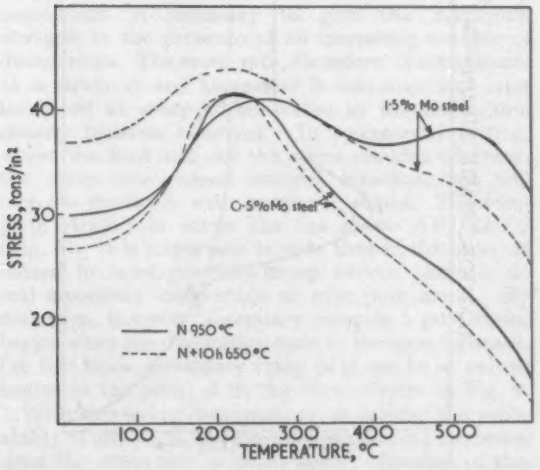


**Fig. 3—Stress for 0·1 strain in 0·5% and 1·5% Mo steels**

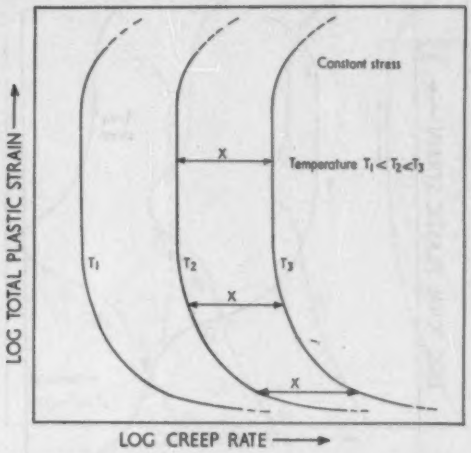


**Fig. 4—Family of constant-stress strain/rate curves for a pure metal**

A further effect must also be considered, namely spheroidization due to the action of time at the testing temperature. In general, the effect of spheroidization is to decrease the creep resistance with increasing time of testing. This aspect has already been discussed in more detail in a previous paper[5] and will not be considered in detail here. It is hoped, however, to publish a further paper on the effect of tempering, indicating the change in the initial and latent creep resistance with tempering, and also the effect of stress and temperature of testing on the results obtained.

From the above considerations it will be appreciated that the shape of the creep curves obtained will vary markedly, depending on the initial conditions of the test material. Obviously no prediction of long-duration properties can be made from short-duration tests unless a fairly complete picture of the effects of the initial creep resistance, latent creep resistance, and spheroidization is known. The above remarks, however, serve to emphasize that structural changes quite apart from simple strain hardening are widespread in commercial alloys.

In many non-ferrous precipitation-hardening alloys the structural changes on tempering (ageing) are more complex than for steel. The loss of alloying elements from solution may be high and grain-boundary precipitation may occur with consequent weakening of adjacent areas. Recrystallization of the matrix can also take place during the process of precipitation. As with steel, however, strain-age hardening occurs in high-temperature tensile tests, indicating that precipitation in the dislocations can occur during straining. The fact that cold work accelerates the rate of ageing during tempering supports this suggestion. It will be assumed meanwhile, therefore, that the mechanism of creep in such alloys is essentially the same as for steel, with the possibility of further complications arising from such phenomena as recrystallization of the matrix during creep testing.

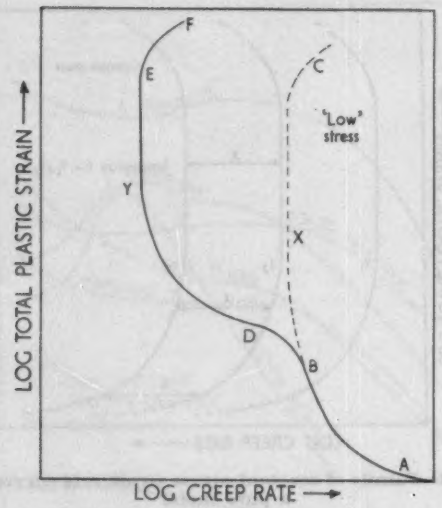


**Fig. 5—'Low'-stress strain/rate curve with one transition**

## OUTLINE OF THEORY

### Pure Metals

Dorn *et al.* postulate[6] that, in a pure metal or a stable alloy where no change in the precipitate occurs during testing the same submicroscopic structures are developed at the same values of $te^{-\Delta H/RT}$ following creep at the same stress to any given value of strain.

Where $t$ = time, $\Delta H$ = activation energy for creep, and $T$ = absolute temperature it follows that:

$$\dot{\epsilon}_1 e^{\frac{\Delta H}{RT_1}} = \dot{\epsilon}_2 e^{\frac{\Delta H}{RT_2}} \quad \text{(strain constant)} \quad \ldots\ldots(1)$$

where $\dot{\epsilon}_1$ and $\dot{\epsilon}_2$ are the creep rates obtained at any given strain on testing at temperatures $T_1$ and $T_2$ respectively. Taking logarithms and transposing:

$$\Delta H = \text{Constant } (\log \dot{\epsilon}_1 - \log \dot{\epsilon}_1)\left(\frac{T_1 \times T_2}{T_1 + T_2}\right) \quad \ldots(2)$$

Thus from creep curves such as in Fig. 1, if the logarithm of creep rate is plotted against total plastic strain (or rather the logarithm of the strain, since this is more convenient), then curves such as in Fig. 4 are obtained. As shown, for any two temperatures the distance X (i.e. $\log \dot{\epsilon}_1 - \log \dot{\epsilon}_2$) is constant for all strains since X is proportional to $\Delta H$. The curve for any other temperature in the range where $\Delta H$ is constant is easily obtained by calculation from the above equation. By integration the ordinary creep/time curve is also obtained. By varying the initial creep resistance the curves in Fig. 4 can be displaced to higher or lower creep rates but their shape remains unaltered.

A pure metal is strain-hardened during creep testing, but this statement is not sufficient for the present purpose. A reasonable assumption is that the strain hardening (or rather dislocation density) increases during creep and becomes constant during secondary creep when there is a balance between the rate of removal and replenishment of dislocations. The ultimate dislocation density is small at low stresses and increases with increase in the stress of testing. It is very large at high stresses, provided rapid recovery or recrystallization do not interfere. (At very low stresses exhaustion creep may occur, but this need not be discussed.) It also follows from the work of Dorn[6] that in constant-stress creep tests on pure metal the dislocation density at any given strain is constant, no matter what the temperature of test is.

The above statement simplifies the strain-hardening aspect of the creep of pure metals but does not explain the basic mechanism of the creep process. Although this is not important as regards this paper it is convenient to assume a 'dislocation climb' mechanism. This implies that dislocations arrested at a barrier undertake a climb process by self-diffusion until they reach a plane where they can move under the applied stress.

### Metals with One Strain-age-hardening Constituent

In an alloy where one strain-age-hardening precipitate can form during straining, both strain hardening and strain-age hardening must be considered. In the condition before testing, the metal has a certain dislocation density. Some, if not all, of these dislocations will contain a dislocation precipitate. (The Cottrell theory would state that each dislocation is surrounded by an atmosphere of solute atoms.) Thus the initial creep resistance is higher than that of a pure metal. Strain hardening is, however, the most important factor in reducing the creep rate in the initial stage of testing, since the movement and multiplication of dislocations is so rapid that strain-age hardening cannot take place. Initially, therefore, the strain/rate curves (curves $AB$ in Figs. 5 and 6) are similar in shape to those of a pure metal (Fig. 4). As the creep rate decreases, however, the rate of formation of dislocations decreases, and because of strain hardening the number

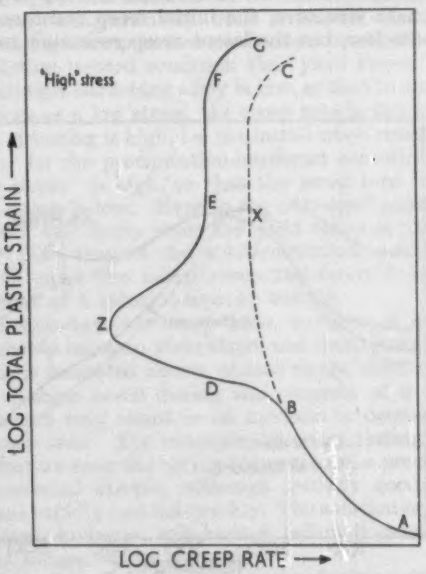


**Fig. 6—'High'-stress strain/rate curve with one transition**

stationary at any instant increases. This allows time for the latent creep resistance (i.e. strain-age hardening) to come into play. The strain-age-hardening constituent will tend to precipitate at points of maximum lattice strain, i.e. points where dislocation climb is most liable to occur. By preventing this climb in a few places, more dislocations can pile up and become stationary, giving more time for further ageing. As a result, the strain-age-hardening process is self-accelerating in a manner similar to that suggested by Cottrell[15] for a single nitrogen-bearing Zn crystal. Because of this, the creep rate slows down rapidly and a transition in creep rate is obtained over the interval *BD* (Figs. 5 and 6). When this transition is complete the strain/rate curve for low stress (Fig. 5) follows a new path which has the same shape as the curve for a pure metal.

In Fig. 5 (low testing stress) a dotted curve *BC* has been added to show the probable strain/rate curve *ABC* which would be obtained if strain-age hardening could be prevented. At some strain $X$ on this curve the creep rate becomes constant, as does also the dislocation density, but because the stress is low this dislocation density is small and there is more than sufficient of the strain-ageing constituent to provide precipitates for all the available dislocations. Thus, the creep rate becomes constant at a strain $Y$, which is greater than $X$. At a much higher strain the creep rate again accelerates because of grain-boundary creep,[6] but more usually because in ordinary testing the stress increases as the test-piece thins down. The complete strain/rate curve thus has the shape *ABDYEF*.

At higher stresses (Fig. 6) a similar argument applies to the initial stages of testing. Because of the higher stress the ultimate dislocation density is greater and the strain at which ageing begins is greater compared with the test at a low stress discussed above. Once strain-age hardening begins, there are many more points at which a precipitate can form. As a result all the strain-age-hardening constituent is used up at a strain $Z$, which is less than $X$. Thus, as testing continues beyond a strain $Z$, more dislocations form so that a continual redistribution of the strain-ageing constituent is necessary to give the maximum strength in the presence of an increasing number of dislocations. The creep rate, therefore, is a minimum at a strain $Z$ and thereafter it increases and later levels off at some higher value as the dislocation density becomes constant. In commercial testing, where the load and not the stress remains constant, the creep rate cannot become constant, but will increase gradually with increasing strain. The complete strain/rate curve has the shape *ABDZEFG* (Fig. 6). It is important to note that in this case, as indeed in most practical creep curves, there is no real secondary creep stage as with pure metal. By definition, however, secondary creep in a pure metal begins when the dislocation density becomes constant. On this basis, secondary creep (if it can be so called) begins at the point $E$ in the curve shown in Fig. 6.

With increasing temperature of testing the probability of any particular dislocation climbing increases, since the creep rate is much faster. Because of this the strain-age-hardening constituent has less tendency

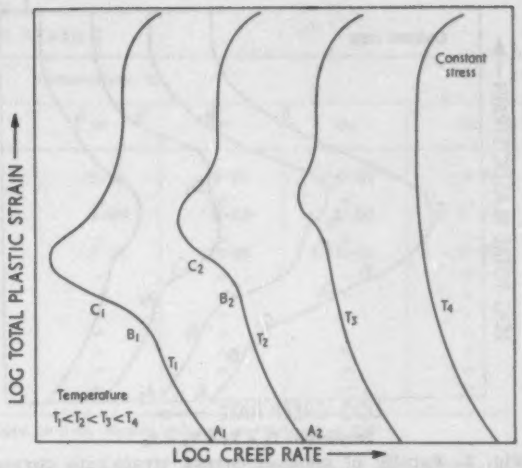


**Fig. 7—Family of constant-stress strain/rate curves with one transition**

to precipitate. Thus the transition in creep rate occurs at a greater strain value the higher the temperature of testing. For the same reason the effect of strain ageing on the shape of the strain/rate curve becomes less pronounced with increasing temperature until above a certain temperature the transition in creep rate disappears.

A family of strain/rate curves at a constant stress and various temperatures, similar to the curve in Fig. 5, could be constructed, but since this case is seldom encountered in practice discussion will be confined to the types of curve obtained at higher stress levels. A family of such curves is shown in Fig. 7. At the lowest temperature of testing $T_1$ a transition in creep rate occurs as before over the interval $B_1C_1$. At the next higher temperature of testing $T_2$, strain-age hardening is about to begin at the point $B_2$. But at this strain in the lower-temperature test, strain-age hardening is approaching completeness. Thus, the submicroscopic structure in the two tests at this level of strain is different, even assuming that the dislocation density itself is the same. This means that the activation energy for creep must be greater for the lower temperature of test at this level of strain, so that the strain/rate curves diverge as the strain increases. In a pure metal, as already shown (Fig. 4) the distance between the curves remains constant.

At all but the highest temperature of testing in Fig. 7 the creep rate reaches a minimum value and thereafter increases; later it reaches a constant value as the dislocation density becomes constant. In pure metals the dislocation density at high strains is constant for all temperatures of testing and probably this is also true in the present case. For this reason the submicroscopic structures at all temperatures will tend to reach similarity at high strain levels. They can never become identical since there is no strain-age hardening in the test at the highest temperature. The activation energy is a maximum for any particular test at the point of minimum creep rate. It then decreases as the strain increases and tends to approach a constant value for all temperatures of test, as was

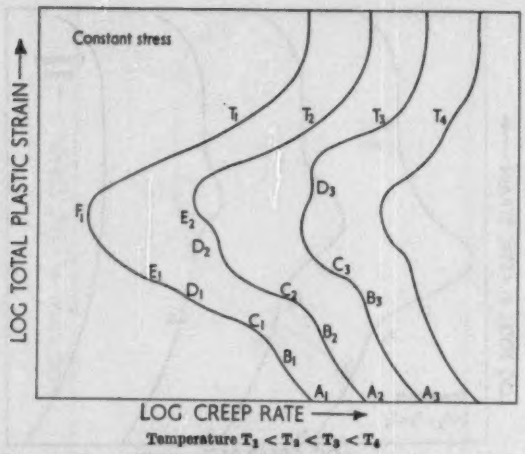


**Fig. 8—Family of constant-stress strain/rate curves with two transitions**

the case for pure metals at all strain levels. For the reason given above, however, the activation energy at high strains never reaches equality. It is always somewhat greater the lower the temperature of test.

As was indicated with reference to pure metals, the activation energy for creep may change above a certain temperature where rapid recovery or recrystallization can occur. A similar effect takes place with commercial alloys at high testing temperatures, which is easily detectable by the change in shape of the strain/rate curves obtained.

In the above example representing a metal with one strain-age-hardening constituent, such as carbon in Fe, it is impossible to obtain a transition in creep rate if it has not occurred by the time the density of dislocations has become constant. (Temperature $T_4$ or higher in Fig. 7.) If the strain-ageing constituent is more complex, as is the case with 'manganese carbide' or molybdenum carbide in iron,[4] strain-age hardening is dependent on the rate of diffusion of the alloying element as well as that of carbon. Even in the absence of strain hardening, precipitation of alloy carbide by replacement of iron carbide may occur in such cases if sufficient time is given. With a high alloy content this gives rise to precipitation hardening as ordinarily defined. Thus, in such alloys a transition in creep rate is possible, even when the creep rate is accelerating.

### Metals with Two Strain-age-hardening Constituents

The rate of strain-age hardening is accelerated if the degree of strain hardening is increased, i.e. if the testing stress is increased, since there are more dislocations in which a precipitate can form. Similarly in precipitation-hardening alloys, the rate of precipitation is increased by increasing the strain hardening, since this increases the rate of diffusion of the alloying element. In this case, therefore, the strain-age hardening might be called strain-induced precipitation. Since this form of strain-age hardening is accelerated by strain hardening, it will occur quite quickly at low temperatures if the testing stress is high enough. For example, strain ageing due to precipitation of manganese carbide occurs during the half-hour taken to break a short-duration tensile test at 300° C, as it gives a maximum in stress at about that temperature.[4] Under creep conditions, however, at a temperature higher than 300° C, strain ageing due to manganese carbide may take a long time to come into play, the time being longer the lower the stress of testing. For example, as was shown in a previous paper,[5] it requires no less than 550 h at 450° C with a stress of 5 tons/in$^2$ before strain ageing due to Mn begins.

Strain/rate curves at constant stress and various temperatures for an alloy with two strain-age-hardening constituents are shown in Fig. 8, the second being of the complex type, i.e. like molybdenum carbide in steel. The first transition in creep rate has similar characteristics to the one shown in Fig. 7. At the lowest temperature of testing $T_1$ in Fig. 8, strain ageing due to the first constituent is still proceeding at the point $D_1$. At this strain, however, strain ageing due to the second constituent begins, giving rise to a second transition in creep rate over the interval $D_1E_1$. As the strain increases, strain-age hardening due to the two constituents proceeds simultaneously. At some higher strain, however, strain ageing due to the first constituent is complete, and with further straining its effect is less because it has to redistribute itself over a larger number of dislocations. The creep rate, however, still decreases for some time owing to strain ageing of the second constituent, but because of the decreasing effect of the first constituent it will reach a minimum value at a point $F_1$ before strain ageing due to the second constituent is complete. The creep rate then increases with further strain, but, as before, will tend later to level off to a constant value.

At the next higher temperature of testing $T_2$ conditions are similar except that strain ageing due to the first constituent has nearly reached completion when the second transition in creep rate begins. At the next temperature $T_3$ the creep rate is increasing when the second transition begins. Even so, the effect of the second strain-ageing constituent is strong enough to halt the acceleration of creep rate and again to decrease it for some time before it begins to accelerate once more. At the highest temperature of testing $T_4$, the creep rate, once it begins to accelerate, continues to accelerate until it eventually reaches a constant value. The strain-age-hardening effect of the second constituent, however, is still detectable.

In a similar manner three or more strain-age-hardening constituents may operate during creep testing by adding additional transitions in creep rate and further complicating the shape of the strain/rate curves.

### Effect of Heat-treatment

The microstructure of an alloy can vary widely, depending on the heat-treatment given to the test material. Close control of the final heat-treatment, however, is not a guarantee of identical microstructure, even in the case of two batches of material from the same cast. The 'heat-treatment' effect of prior processing must also be considered, particularly in the case of complex alloys. Wood and Rait,[16] for example, showed that a high-temperature treatment given to a 3%Cr–Mo–V–W steel before the normal oil

**Table I**
**MANGANESE STEELS**

| Steel | Al, lb/ton | Composition, % | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | C | Si | Mn | Ni | Cr | Mo | Cu |
| 1 | 3 | 0·09 | 0·05 | 0·12 | <0·01 | <0·01 | <0·01 | <0·01 |
| 2 | ½ | 0·095 | 0·06 | 0·15 | ,, | ,, | ,, | ,, |
| 3 | 3 | 0·08 | 0·07 | 0·14 | 0·09 | 0·03 | 0·02 | 0·15 |
| 4 | ½ | 0·08 | 0·06 | 0·17 | ,, | ,, | ,, | ,, |
| 5 | 2 | 0·11 | 0·16 | 0·40 | <0·01 | <0·01 | <0·01 | <0·01 |
| 6 | Nil | 0·13 | 0·16 | 0·35 | ,, | ,, | ,, | ,, |
| 7 | 2 | 0·10 | 0·10 | 0·59 | ,, | ,, | ,, | ,, |
| 8 | Nil | 0·11 | 0·12 | 0·56 | ,, | ,, | ,, | ,, |
| 9 | 2 | 0·10 | 0·12 | 1·06 | ,, | ,, | ,, | ,, |
| 10 | Nil | 0·09 | 0·09 | 1·04 | ,, | ,, | ,, | ,, |
| 11 | 2 | 0·10 | 0·16 | 1·64 | ,, | ,, | ,, | ,, |
| 12 | Nil | 0·11 | 0·11 | 1·58 | ,, | ,, | ,, | ,, |

**All steels were of the 18 lb H.F. type. Ingots were forged to 1-in. square bar and normalised at 950° C**

quenching and tempering treatment changed the resulting microstructure considerably and therefore changed the initial creep resistance.

Cold working or 'warm working' after heat-treatment also influences the submicroscopic structure. Both these processes will alter the dislocation density but may also result in a varying degree of strain-age hardening or strain-induced precipitation, with a consequent increase in initial creep resistance.

In general, however, it can be stated that whatever the original microstructural condition of an alloy, the same number of transitions in creep rate will be obtained. The amount of strain-age-hardening constituent available for precipitation during creep testing may, however, vary greatly so that the latent creep resistance also varies depending on the original microstructure of the alloy. No attempt is made in the paper to investigate this aspect of the problem in detail.

**Effect of Varying Stress**

In the foregoing the emphasis has been placed on tests at constant stress and various temperatures. In general, such tests are more suitable for extrapolation purposes than tests at constant temperature because in constant-stress testing the strain hardening at any given strain is reasonably constant. For applications involving small deformations the constant-stress method of testing is particularly useful.

In tests at constant stress the strain/rate curves obtained are nearly parallel at low strain levels. In constant-temperature tests this no longer holds since the initial plastic strain increases rapidly as the stress of testing is increased. Thus, the strain hardening in the initial stages of testing increases rapidly with increased stress of testing, as also does the dislocation density. Since strain hardening accelerates ageing, the shape of the strain/rate curves will vary considerably with stress. In extreme cases at high stress some strain-ageing constituents are attenuated so greatly, owing to the high density of dislocations, as to contribute little or nothing to the strength, even though they may have a large effect below some lower stress.

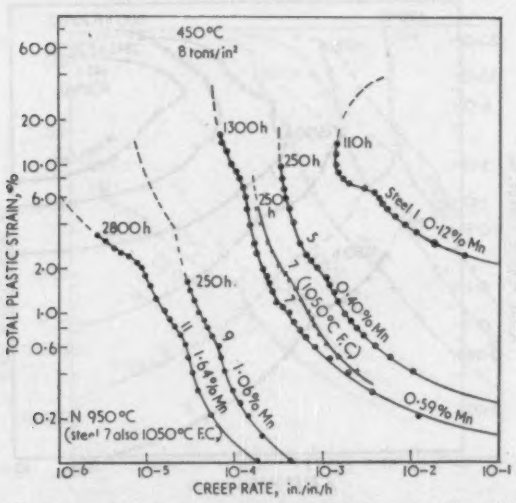


**Fig. 9—Strain/rate curves on Al-killed steels with various Mn contents**

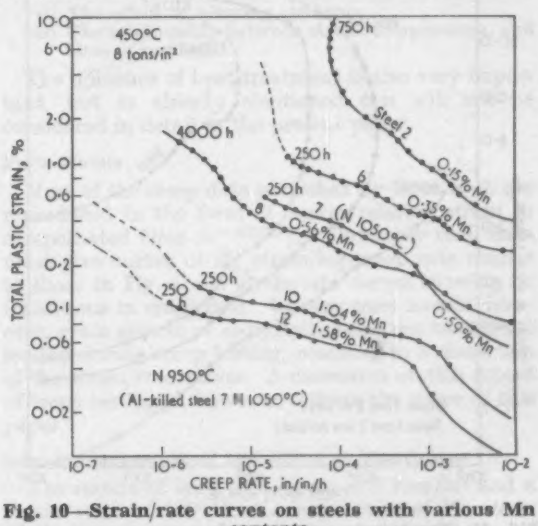


**Fig. 10—Strain/rate curves on steels with various Mn contents**

**Table II**
**MANGANESE STEELS**

| Steel | Type | Form | Al, lb/ton | Composition, % | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | C | Si | S | P | Mn |
| 13 | Basic O.H. | 1-in. dia. | 2½ | 0·11 | 0·05 | 0·027 | 0·012 | 0·45 |
| 14 | ,, | ,, | 1 | 0·12 | 0·06 | 0·039 | 0·015 | 0·52 |
| 15 | ,, | 1-in. plate | 2 | 0·13 | 0·15 | 0·028 | 0·025 | 1·02 |
| 16 | ,, | ,, | Nil | 0·13 | 0·04 | 0·018 | 0·026 | 1·00 |
| (Ref. 17) | Acid O.H. | Header | Nil | 0·24 | 0·10 | 0·032 | 0·040 | 0·61 |
| 17 | Basic O.H. | 3-in. plate | Nil | 0·135 | 0·14 | 0·036 | 0·020 | 1·20 |

All steels were tested in the normalised condition except steel 17, which was also tempered 2 h at 650° C

For example, in short-duration tensile tests at temperatures above 300° C an aluminium-killed steel is as strong as an ordinary steel of the same composition, even though at 200° C it is inferior.[4] This means that, at high temperature, strain ageing due to nitrogen in the ordinary steel is attenuated because of the high density of dislocations and has little effect. On the other hand, under creep conditions where the dislocation density is low, the ordinary steel is better since the nitrogen has a powerful effect on the small number of dislocations present.

Although by testing at constant temperature and various stresses other factors such as variation in strain hardening are introduced, the pattern of strain/rate curves obtained clearly shows these variations. In practice, therefore, both methods of testing have their own advantages depending on the alloy being tested and the information required.

**Extrapolation**

If a series of creep tests at constant stress and various temperatures is carried out on a particular alloy and the strain/rate curves calculated, it is possible from the pattern of curves so obtained to estimate the strain/rate curve for the same stress at several lower temperatures. The initial part of the curves may be checked by experiment. From these strain/rate curves it is then possible to calculate the ordinary strain/time curves. Finally, by plotting iso-strain curves of temperature against log time, the temperature for any given strain in, say, 100,000 h can be obtained.

Similarly, from strain/rate curves of tests at constant temperature and various stresses, estimates of the strain/rate curves for lower stresses can be made and similarly treated. Examples of such extrapolations have already been given.[5]

In the above a simple mechanism for the creep resistance of complex alloys has been postulated. No doubt this mechanism will need modification as the theories of strain hardening, strain-age hardening, and precipitation hardening are further developed. It should be appreciated also that in some cases other structural changes may interfere, particularly if the temperature of testing is high. These will include recovery, recrystallization, discontinuous precipitation, and ordinary time-induced precipitation. In

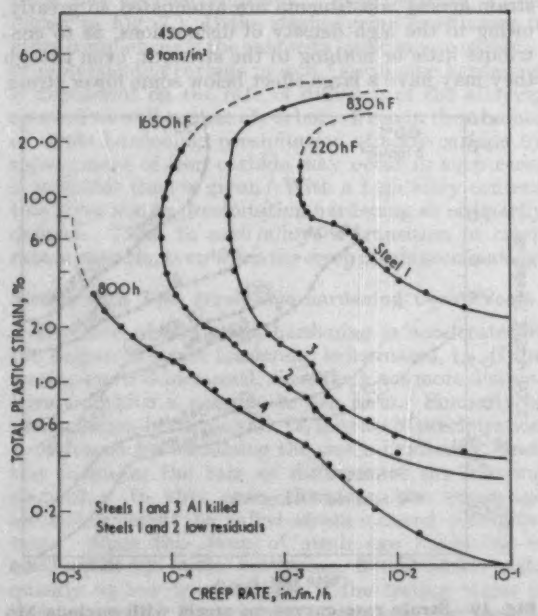


Fig. 11—Strain/rate curves on low-manganese steels

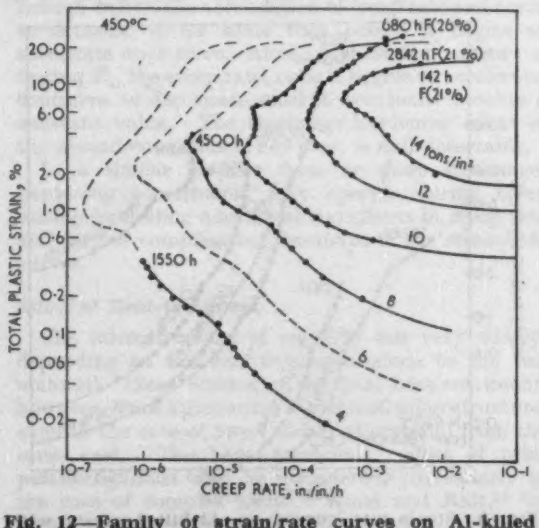


Fig. 12—Family of strain/rate curves on Al-killed 0·5%Mn steel 13

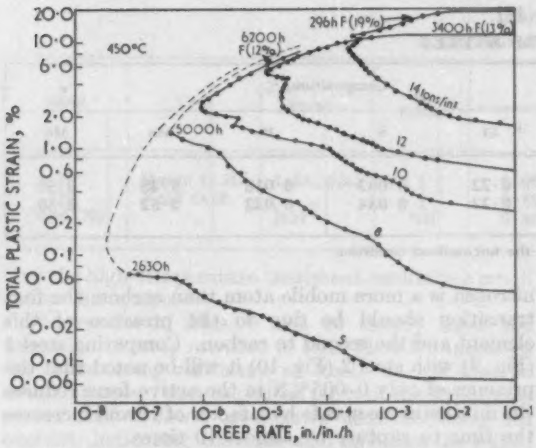


Fig. 13—Family of strain/rate curves on 0·5% Mn steel 14

such cases the discrepancies will be obvious from the strain/rate curves obtained and can be further investigated. The difficulties of testing should also be realized. Since strain hardening induces strain ageing, a slight degree of non-axial loading will alter the results obtained, this effect being more important the smaller the permissible deformation. The time at temperature before testing may also be important in some cases. Ideally, heating to temperature and loading should be instantaneous, though this is obviously impossible. By holding at a testing temperature above the service temperature for any appreciable time the alloy is 'tempered' and precipitation of some constituent may occur and increase the initial creep resistance. At a lower temperature the same time at temperature before testing may have little or no effect.

Having given a simple theoretical explanation of the expected behaviour of commercial alloys, all that remains is to give a detailed experimental proof using

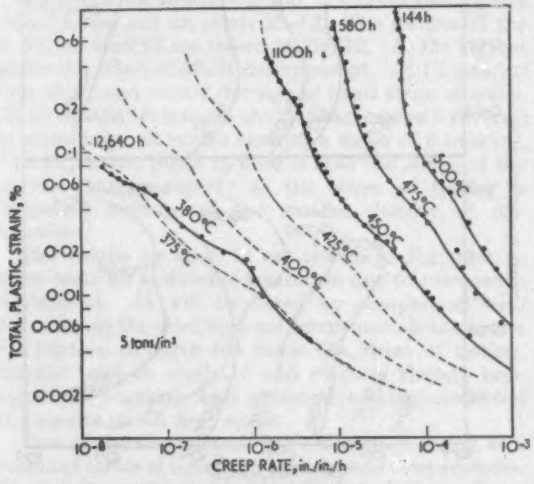


Fig. 14—Family of strain/rate curves at 5 tons/in² on Al-killed 1% Mn steel 15

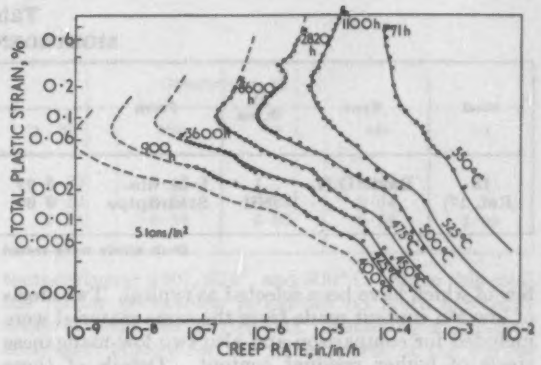


Fig. 15—Family of strain/rate curves at 5 tons/in² on 1% Mn steel 16

log strain/log creep curves to present the data. This evidence is given in the remaining part of this paper.

## EXPERIMENTAL EVIDENCE

A search of the literature reveals that only a limited number of steels and other alloys have been systematically creep tested either at constant stress or constant temperature. Even in such cases, and where individual test results are reported, the data are often given in summarized form so that an accurate estimate of creep rate at various strains cannot be obtained. For the most part, therefore, the author has made use of his own results. Fortunately it has been possible to obtain creep data from other sources to augment the results and to provide evidence of the behaviour of more complex alloys. Such results also provide independent confirmation of the observed phenomena.

It should be realized also that the theoretical implications were not fully understood at the time many of the tests were being carried out, so that some tests were discontinued before all the ageing effects were complete. An attempt has been made, however, to select data to illustrate the following main points:

(i) The effect of alloying elements
(ii) The relationship between stress, temperature, and time of testing.

The influence of heat-treatment is also very important, but as already mentioned this will not be considered in detail in the present paper.

### Pure Metals

Most of the creep data published by Dorn *et al.* are reproduced in the form of curves relating strain to compensated time ($te^{-\Delta H/RT}$). Obviously such data must give curves of log strain/log creep rate similar to those in Fig. 4, i.e. strain/rate curves showing no transitions in creep rate. In very pure metals, however, grain growth or recrystallization can take place readily during creep testing, resulting in a distortion of the strain/rate curves. A discussion on this aspect of creep testing is, however, outside the scope of this paper.

### Low-manganese Steel and Effect of Manganese

The results of tests at a stress of 8 tons/in² and a temperature of 450° C on a large series of Mn steels made from very pure Armco iron were available,[2] a

**Table III**
**MOLYBDENUM STEELS**

| Steel | Type | Al, lb/ton | Form | Composition, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | C | Si | S | P | Mn | Mo |
| 18 (Ref. 17) | Basic O.H. | ½ | 1-in. dia. | 0·09 | 0·22 | 0·032 | 0·018 | 0·48 | 0·50 |
| | „ | Nil | Steampipe | 0·09 | 0·22 | 0·034 | 0·023 | 0·52 | 0·50 |

Both steels were tested in the normalized condition

few of which have been selected as typical. Two steels of low Mn content made from the same material were included for comparison and also two low-manganese steels of higher residual content. Details of these steels are given in Table I. Half the steels were deoxidized with Al and normalized so that most of the nitrogen present (0·005%) was in the form of aluminium nitride and was not available to cause strain-age hardening. These alloys thus approximate to Fe–C–Mn alloys.

From the creep data strain/rate curves were obtained in the manner already described.[5] The results for the aluminium-killed steels are shown in Fig. 9. Pecked lines have been added to indicate the probable trend in longer testing times. Considering first the very low-manganese steel 1, it will be noted it shows only one transition in creep rate, which can be attributed to strain-age hardening by precipitation of iron carbide in the dislocations. The other steels in Fig. 9 show two transitions, one as above and the second in longer testing times, which can be attributed to the presence of Mn. As was shown for tensile testing,[4] the strain-age hardening in this case probably results from some form of coherent precipitation of manganese carbide in the dislocations.

Figure 10 shows similar results on the Fe–N–C–Mn alloys. Steel 2 with low Mn shows two transitions in creep rate, one resulting from carbon as above and the other due to precipitation of iron nitride. Since nitrogen is a more mobile atom than carbon, the first transition should be due to the presence of this element and the second to carbon. Comparing steel 1 (Fig. 9) with steel 2 (Fig. 10) it will be noted that the presence of only 0·005%N in the active form reduces the minimum creep rate by a factor of 10 and increases the time to rupture by almost 10 times.

The other steels in Fig. 10 show three transitions in creep rate as might be expected. A comparison of these steels with those in Fig. 9 shows that active nitrogen reduces the creep rate markedly. The effect of nitrogen is also clearly demonstrated by suitable heat-treatment of the aluminium-killed steels. For example, the aluminium-killed steel 7 was tested after normalizing at 1050° C, and also after very slow cooling from the same temperature. At 1050° C most of the aluminium nitride has dissolved and does not re-form during air cooling. Thus all the nitrogen is in the active form so that, as shown in Fig. 10, this steel compares favourably with a similar steel not deoxidized with Al. By slow cooling from 1050° C aluminium nitride has time to re-form, so that the creep resistance is no better than that of the same steel normalized at 950° C (Fig. 9), despite the fact

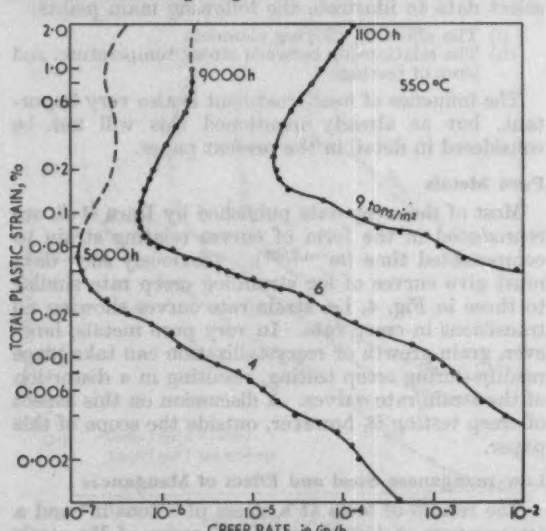


Fig. 16—Strain/rate curves on 0·5%Mo steel 18

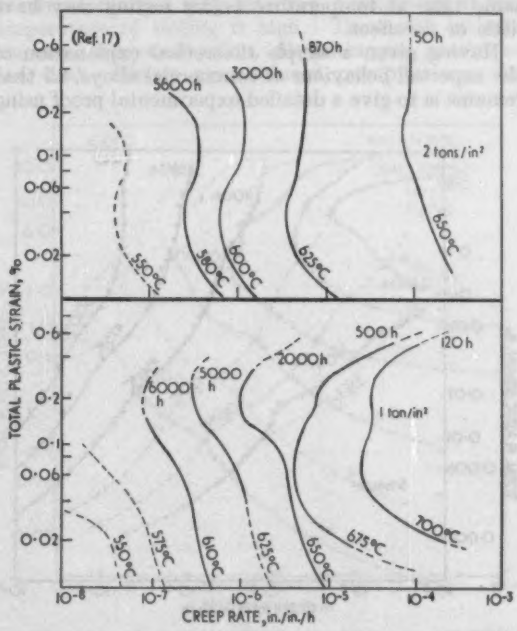


Fig. 17—Families of strain/rate curves on 0·5%Mo steel

**Table IV**
**MOLYBDENUM STEELS**

| Steel | Type | Form | Al, lb/ton | Composition, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | C | Si | Mn | Cr | Mo | Ni |
| 18 | Basic O.H. | 1-in. dia. | ½ | 0·09 | 0·22 | 0·48 | ... | 0·50 | ... |
| 19 | Acid O.H. | „ | ½ | 0·10 | 0·14 | 0·51 | 0·82 | 0·54 | ... |
| (Ref. 20) | ... | Bar | Nil | 0·31 | 0·11 | 0·54 | 0·83 | 0·54 | 2·05 |

that the high-temperature treatment results in a much coarser structure.

The results in Figs. 9 and 10 clearly show the transition in creep rate due to Mn. Thus Mn increases the latent creep resistance of steel. It will also be noted, however, that the initial parts of the strain/rate curves shift to lower creep rates with increasing Mn content, indicating that Mn also increases the initial creep resistance markedly. This must be mainly due to solution hardening and the prevention of rapid recovery.

The effect of residual alloying elements is shown in Fig. 11, which compares steels 1 and 2 with steels 3 and 4. The residual elements increase the initial creep resistance without affecting the number of transitions. The presence of residuals is also important in steels of higher Mn content. This is clear from the creep tests reported in a previous paper,[2] so that there is no need to reproduce the results here. It should be emphasized, however, that the important strengthening effect of residual alloying elements or the deliberate addition of such elements in small amounts has never been thoroughly investigated.

The above data serve to show the importance of Mn but give no indication of its effect at different temperatures and stresses. Some basic O.H. steels have, however, been tested more extensively. Tests on an acid O.H. carbon steel reported by Ridley[17] can also be considered, though the estimates of creep rate in this case are of necessity less accurate. Details of these steels are given in Table II.

Tests at a temperature of 450° C and various stresses were carried out on steels 13–16. The results on the 0·5%Mn steel 13 are shown in Fig. 12. At the highest stress the effect of Mn is not apparent. At 12 tons/in² it is slight and occurs during the third stage of creep. At 10 tons/in² it is more obvious and causes a reversal in creep rate. It is also clear at a stress of 8 tons/in². The important point to note is that the shape of the curves changes rapidly as the stress of testing is decreased because of the smaller density of dislocations.

The results on steel 14 are shown in Fig. 13. In these tests an additional transition due to nitrogen is introduced. It will be noted by comparison with Fig. 12 that the steel with active nitrogen is the better for rupture strength the lower the stress of testing. Similar tests on steels 15 and 16 have already been reported,[5] together with a tentative extrapolation of the results on all four steels.

Two of the above steels have also been tested at a constant stress of 5 tons/in² and various temperatures. The results on the aluminium-killed steel 15 are shown in Fig. 14. Tests were carried out on this steel at three temperatures: 450°, 574°, and 500° C. Since this steel has rather poor creep properties no more extensive series of tests was carried out. Assuming a constant activation energy for the initial parts of the curves and a slightly increasing activation energy at later stages, an estimate was made of the strain/rate curves for several lower temperatures. These are indicated by pecked curves. At a later date the results of a creep test at 380° C on a very similar type of material were obtained[18] and the strain/rate curve was found to agree reasonably well with that predicted.

A more detailed series of tests carried out on steel 16 is shown in Fig. 15. In this case tests were carried out at 25° intervals from 425° to 550° C. From this series it is relatively easy to predict the strain/rate curve for a temperature of 400° C or lower. An important point to note is that the symmetry of the curves changes markedly above about 500° C. This implies that, at this stress, rapid recovery begins in tests above about 500° C. Such tests are of little use in any attempt to predict the long-duration properties at temperatures where this form of recovery is absent.

The results of tests on steel 17 have already been reported.[5] These are very similar to the results in Fig. 15 except that the transitions in creep rate occur at lower strain values, as also does the third stage of creep. This was to be expected because tempering increases the initial creep resistance.

Ridley[17] has reported extensive results of tests on a carbon-steel header at stresses of 5, 2, and 1 ton/in². One test at 5 tons/in² and 450° C lasted 70,000 h. From the published results it is impossible to calculate the creep rates with great accuracy particularly at short testing times. Nevertheless strain/rate curves obtained from this data were of sufficient accuracy to show the general pattern similar to that in Fig. 15.

### Effect of Molybdenum

Although the results of many rupture tests at various stresses and temperatures on 0·5%Mo steel were available,[19] information on the elongation during the time to rupture was not obtained, so that strain/rate curves could not be produced. Also, since Ridley[17] has already reported extensive creep tests on 0·5%Mo steel the author considered it unnecessary to repeat this work, and thus had confined his attention to checking cast-to-cast variation by means of tests at a few different stresses and temperatures.[19] Attention will therefore be confined to one steel which is very similar in analysis and mode of manufacture to the one reported by Ridley. Details of these steels are given in Table III.

The results of tests on steel 17 at a temperature of 550° C and stresses of 9, 6, and 4 tons/in² are shown

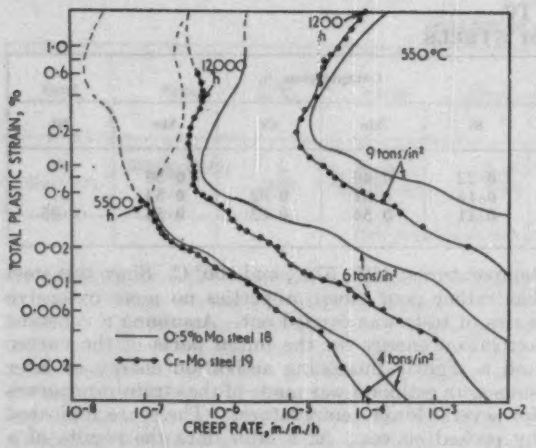


**Fig. 18—Strain/rate curves on Cr–Mo steel 19**

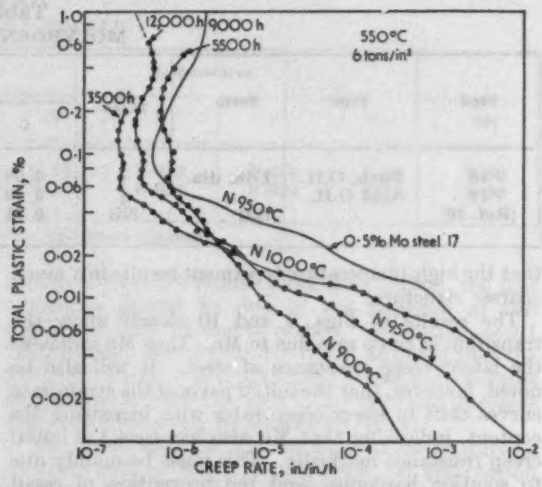


**Fig. 19—Effect of various normalizing treatments on strain/rate curve for Cr–Mo steel 19**

in Fig. 16. In each strain/rate curve three transitions in creep rate are obtained owing to the presence of nitrogen, carbon, and manganese. A fourth transition seems to have been beginning in the test at 6 tons/in², when the test was stopped. From the evidence considered below and from the known times to rupture it is known that a fourth transition does occur at a higher strain level. The approximate position of this transition is shown by pecked curves.

Ridley's tests[17] were carried out at stresses of 6, 4, 2, and 1 ton/in². The reported creep data at 2 and 1 ton/in² were used to calculate the strain/rate curves as shown in Fig. 17, but, of course, the fine detail is missing. The strain/rate curves of the results at 6 tons/in² have already been given.[5] The author has, however, carried out a number of short-duration tests which show that three transitions occur in the first few thousand hours. The transition shown in Fig. 17 is thus the fourth transition in this steel and is due to the presence of Mo.

Although only two samples of 0·5%Mo steel of almost identical composition and treatment have been considered, it seems justifiable to conclude that on testing any normal type of 0·5%Mo steel, creep curves showing four transitions in creep rate would be obtained. In an aluminium-killed 0·5%Mo steel, of course, only three transitions will be obtained.

### Effect of Chromium

From the evidence of high-temperature tensile tests[4] it was known that the effect of Cr on the strain-ageing behaviour of a steel was similar to that of Mn, except that the effect of Cr was a maximum at a slightly higher temperature. It is to be expected, therefore, that an additional transition in creep rate due to Cr will be obtained on testing Cr steels and that this transition will begin at a somewhat greater strain than the transition due to Mn.

It has not yet been possible to test simple Cr steels, but fortunately test data on 0·5%Mo steels containing Cr were available which suffice for the present purpose. Details of one of these steels and a comparable steel without Cr are in Table IV. Analyses of a steel tested by Robinson[20] are also included.

Figure 18 shows the results of tests on steel 19 at a temperature of 550° C and stresses of 4, 6, and 9 tons/in². The results on steel 18 are included for comparison. In these tests a transition in creep rate begins at about 0·04% strain at 4 tons/in², 0·09% strain at 6 tons/in², and 0·4% strain at 9 tons/in². The curves for steel 18 do not show this transition so that it is obviously related to the presence of Cr. The transition in creep rate due to Mo occurs at still higher strains as was shown in Fig. 16. This transition was just beginning in the test at 6 tons/in² when the test was stopped. The approximate position of the Mo transition is shown by pecked curves.

It is interesting to consider the tests at 4 tons/in² shown in Fig. 18. Up to 5000 h the strain/rate curves of the two steels are nearly identical and so also, of course, are the ordinary creep curves. The pecked curves showing the probable trend of the strain/rate curves in longer testing times diverge. This must be the case since the time to rupture of the Cr–Mo steel 19 at this stress and temperature was 68,000 hours, compared with only 25,000 hours for the 0·5%Mo steel 18.[19] It is, of course, the effect of Cr on the

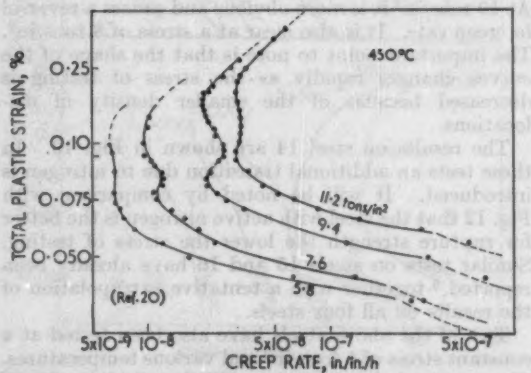


**Fig. 20—100,000-h strain/rate curves on Ni–Cr–Mo steel**

## Table V
### VANADIUM AND TITANIUM STEELS

| Steel | Type | Al, lb/ton | Treatment | Composition, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | C. | Si | Mn | Mo | V | Ti |
| 7 | H.F. | 2 | N. 950° C | 0·10 | 0·10 | 0·59 | ... | ... | ... |
| 18 | Basic O.H. | ¼ | (a) N. 950° C<br>(b) N. 5 h 690° C | 0·09 | 0·22 | 0·48 | 0·50 | ... | ... |
| 20 | H.F. | 2 | N. 950° C | 0·11 | 0·08 | 0·53 | 0·51 | ... | ... |
| 21 | H.F. | Nil | N. 950° C | 0·12 | 0·04 | 0·60 | ... | 0·23 | ... |
| 22 | H.F. | Nil | + 5 h | 0·115 | 0·05 | 0·54 | ... | 0·465 | ... |
| 23 | H.F. | Nil | 690° C | 0·135 | 0·09 | 0·48 | ... | 1·14 | ... |
| 24 | Basic O.H. | 2 | (a) N. 950° C + 5 h 750° C<br>(b) W.Q. 1150° C + 5 h 750° C | 0·075 | 0·08 | 0·35 | ... | ... | 0·27 |
| 25 | E.F. | ¼ | N. 1050° C + 5 h 690° C | 0·10 | 0·12 | 0·56 | 0·53 | 0·22 | ... |
| 26 | H.F. | 2 | N. 1150° C + 5 h 750° C | 0·10 | 0·31 | 0·49 | 0·52 | 0·25 | 0·28 |

All steels were in the form of 1-in. dia. bar

latent creep resistance which causes this difference.

Three samples of steel 9 were also tested after normalizing at different temperatures. The results are shown in Fig. 19. As in Fig. 18 the transition in creep rate due to Cr begins at about 0·09% strain. It is also interesting to note that with a low normalizing temperature the initial creep resistance is better than that of a test normalized at a higher temperature. At about 0·02% strain, however, the strain-rate curves cross so that the steel normalized at the highest temperature becomes the best, i.e. it has the highest latent creep resistance.

Before concluding the discussion on the effect of Cr, mention must be made of four 100,000-h creep tests reported by Robinson.[20] These tests at four different stresses and at a temperature of 450° C were carried out on a Ni–Cr–Mo steel. By careful measurement and plotting of the points given on the original curves and drawing smooth curves through these points, it was possible to obtain the strain/rate curves shown in Fig. 20. As before, the fine detail at the beginning of the tests is missing but there seems little doubt that the final transition shown results from the presence of Cr. At this temperature the effect of Mo would be apparent only after still longer testing times. The similarity of behaviour of the four tests shows the remarkable accuracy achieved many years ago by measuring equipment which would now be considered as archaic.

### Effect of Vanadium and Titanium

A study of the literature suggests that the addition of V or Ti to a simple C–Mn steel does not result in as good a creep resistance as the addition of Mo. Some support for this conclusion is given by the results of high-temperature tensile tests[4] which show that, unlike Mo, V or Ti in steel do not give rise to strain-age hardening, at least at temperatures up to 650° C. On the other hand, the presence of these elements in solution modifies the strain-age-hardening behaviour at temperatures below 650° C. For example, the author has suggested[4] that strain ageing due to Mn is effective up to a higher temperature when V or Ti is present in the steel.

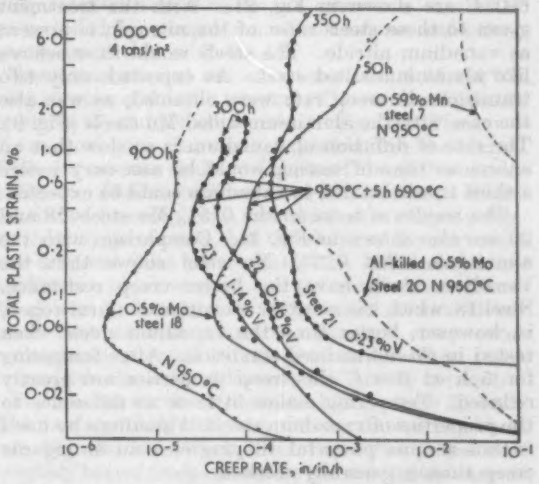


Fig. 21—Strain/rate curves on vanadium steels

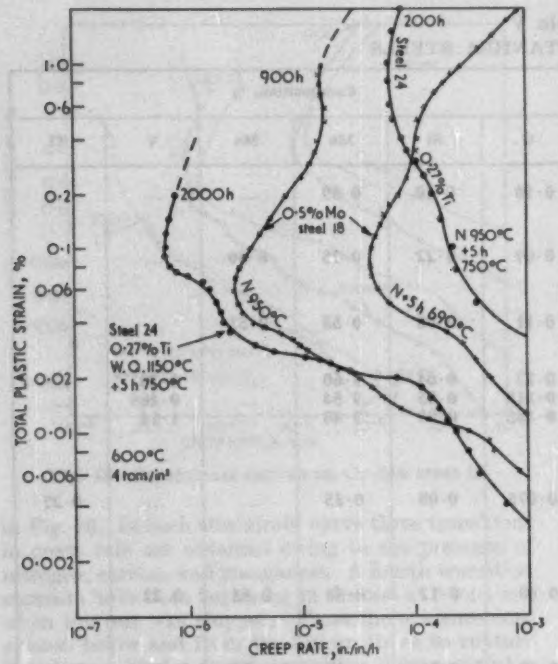


**Fig. 22—Strain/rate curves on titanium steel 24**

As will be shown, the effect of V and Ti may vary, depending on the heat-treatment given to the steel. Two extremes of treatment were thus chosen for the tests reported in this paper. With one the steels were spheroidized and in the softest possible condition. The other treatment used resulted in a higher tensile strength as well as giving good creep resistance. Three vanadium steels, a Ti steel, a Mo–V steel, and a Mo–V–Ti steel were tested. The analyses and other details are given in Table V together with those of two 0·5%Mo steels and a C–Mn steel which were used for comparison.

The results of tests on the vanadium steels 21, 22, and 23 at a stress of 4 tons/in² and a temperature of 600° C are shown in Fig. 21. With the treatment given to these steels most of the nitrogen is present as vanadium nitride. The steels would thus behave like aluminium-killed steel. As expected, only two transitions in creep rate were obtained, as was also the case with the aluminium-killed Mn steels (Fig. 9). The rate of diffusion of vanadium is so slow that an enormous time of testing would be necessary before a third transition due to vanadium could be expected.

The results of tests on the 0·5% Mo steels 18 and 20 are also shown in Fig. 21. Comparison with the aluminium-killed 0·5% Mo steel shows that the vanadium steels have the better creep resistance. Steel 18, which has an extra transition due to nitrogen, is, however, better than the vanadium steels when tested in the normalized condition. After tempering for 5 h at 690° C the creep properties are greatly reduced. Tempering makes little or no difference to the properties of vanadium steels. Vanadium by itself is thus a more powerful alloying element as regards creep than is generally realized.

As is also shown in Fig. 21, the creep rate of the vanadium steels is about one-thousandth of that of the aluminium-killed C–Mn steel 7 tested under the same conditions. It might be said that this is simply the solution-hardening effect of vanadium. What appears more likely is that, because vanadium increases the recovery temperature and because of its affinity for carbon in solution, the strain-age hardening due to carbon and Mn is more effective in reducing the creep rate. Such an explanation would also explain the results of high-temperature tensile tests. It will be appreciated from the data already presented that Mn–Cr and Mo have a similar though less effective influence on the strain-age hardening due to other constituents.

The results obtained on the Ti steel 24 are shown in Fig. 22. These tests were also carried out at a stress of 4 tons/in² and a temperature of 600° C. Titanium has a very powerful affinity for nitrogen so that even if the steel had not been deoxidized with Al, the steel, when tested in the normalized and tempered condition, would have behaved like an aluminium-killed steel. As is evident, the conclusions reached from the results on the vanadium steels apply equally to the Ti steel in the above condition of heat-treatment.

By heating the Ti steel 24 to 1150° C titanium carbide and nitride go into solution. If the steel is water quenched from this temperature titanium carbide and nitride do not re-form during cooling. By tempering at 750° C some precipitation hardening takes place. In this condition a very high creep resistance is obtained, as is shown by the result in Fig. 22. It is interesting to note that in this test an additional transition in creep rate makes its appearance. This can be attributed to the presence of active nitrogen. It would appear, therefore, that even after 5 h tempering at 750° C all the nitrogen in solution after water quenching is not removed in the form of aluminium or titanium nitride.

Figure 23 shows the results of tests on the more complex steels at a stress of 4 tons/in² and a temperature of 600° C. The strain/rate curve for the Mo–V steel 25 has 4 transitions in creep rate, the same

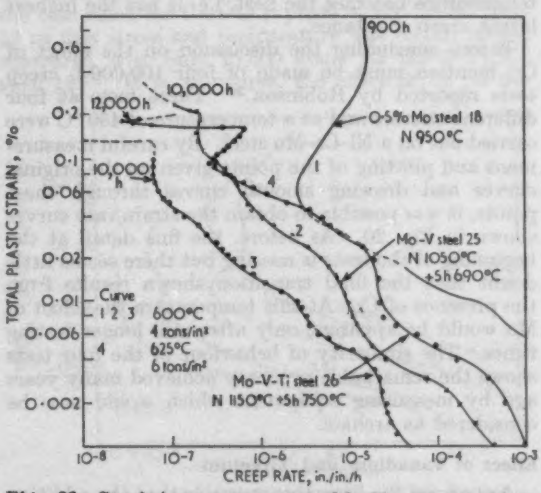


**Fig. 23—Strain/rate curves on Mo–V and Mo–V–Ti steels**

number as was obtained on the 0·5%Mo steel 18, which, however, did not have as good a creep resistance. The fourth transition in steel 25 begins at about 0·2% strain compared with about 0·6% strain for the 0·5%Mo steel. In both cases, however, this transition seems due to the presence of Mo. Even after 10,000 h of test only three transitions were detected in the strain/rate curve for the Mo–V–Ti steel 26 at the above stress and temperature. A very pronounced fourth transition is indicated by a pecked curve. This extrapolation is probably correct since a test on the same steel at a stress of 6 tons/in² and a temperature of 625° C shows a pronounced fourth transition at about 0·16% strain. The result of this test is also shown in Fig. 23.

The above data indicates that V and Ti, as alloying elements, are more effective in the presence of other alloying elements and when the treatment of the steel is such as to leave some nitrogen in solution. The strain-age-hardening effect of other elements seems to be intensified by the presence of V or Ti. In the complex steels these elements also increase the initial creep resistance, since with the treatment given, a very finely dispersed precipitate is obtained which does not spheroidize readily.

An interesting feature of the results on the above steels is the influence of nitrogen. Depending on the treatment given to the steels, nitrogen may have no influence on the creep rate or, if there is sufficient in solution, the creep rate may be reduced by a factor of 10 or even more during the nitrogen transition. Evidence from high-temperature tensile tests[4] suggests that a somewhat similar effect may occur in simpler steels, particularly those containing Cr. The total nitrogen content may vary from cast to cast and with the method of manufacture. For example, electric-furnace steel usually has a higher nitrogen content than O.H. steel. If closer control of the nitrogen content of steel could be maintained, as well as the heat-treatment, the variation in creep properties found between different casts of the same type of steel would be reduced considerably. The deliberate addition of nitrogen as an alloying element should also be seriously considered.

**Effect of Silicon**

So far in this paper attention has been confined to alloying elements which form definite carbides in steel. Silicon is not a carbide-forming element and its strengthening effect is usually considered to be due simply to solution hardening. High-temperature

**Table VI**
**SILICON STEELS**

| Steel | Al, lb/ton | Composition, % | | |
|---|---|---|---|---|
| | | C | Si | Mn |
| 27 | Nil | 0·105 | 0·09 | 0·82 |
| 28 | Nil | 0·10 | 1·02 | 0·74 |
| 29 | 2 | 0·11 | 0·05 | 0·72 |
| 30 | 2 | 0·12 | 0·96 | 0·75 |

All steels were of the H.F. type in the form of 1-in. dia. bar and were normalized at 950°C

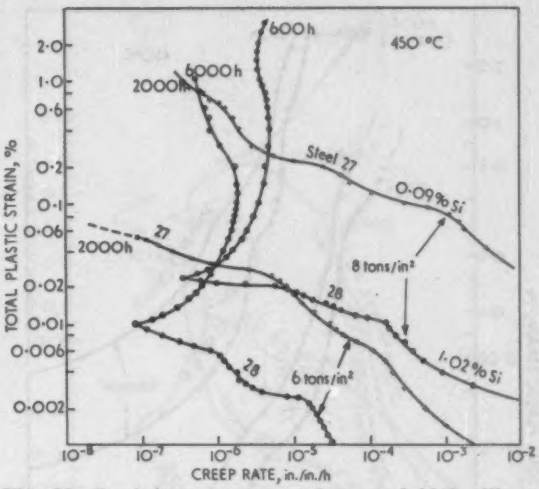


**Fig. 24—Strain/rate curves on low- and high-silicon steels**

tensile tests on a 1%Si steel[4] did not appear to show any strain-age-hardening effect due to Si although the strain-age hardening at about 200° C did seem to increase.

The addition of Si to a steel may, however, drastically change the shape of the creep curves obtained. This is certainly true for C–Mn steel, 0·5% Mo steel, and 1%Cr–0·5%Mo steel.[21] The effect of Si on these steels is to reduce the creep rate markedly in the initial stages of testing and at a later stage to cause a rapid acceleration of creep. Such behaviour cannot be fully explained by solution hardening, so one or other of the following reasons must be correct: either Si does influence the strain-age-hardening behaviour, or it has some other, as yet unknown, effect which has not been included in the theory outlined in this paper.

To illustrate the effect of Si, attention will be confined to two 1%Si steels, one of which was deoxidized with Al. Two other low-silicon steels made under the same conditions and using the same raw materials are included for comparison. The analyses and other details are shown in Table VI.

Tests were carried out at a temperature of 450° C using stresses of 6 and 8 tons/in². The results obtained for steels 27 and 28 are shown in Fig. 24. The low-silicon steel gave the result expected and the shape of the curves was similar to those of the C–Mn steels in Fig. 9. The high-silicon steel 28 also shows three transitions in creep rate, the third occurring during the third stage of creep, but the shape of the curves is very different from those of steel 27. The creep rate rapidly falls to a low value and then begins to accelerate after only 0·01% or 0·02% strain. It should be noted that at the point of minimum creep rate the high-silicon steel is creeping at less than one-thousandth the rate of the steel of low Si content.

The results on the aluminium-killed steels 29 and 30 show an entirely different picture. It will be noted from Fig. 25 that although the high-silicon steel has a slightly better creep resistance the strain/rate curves of the two steels have the same shape, which is similar

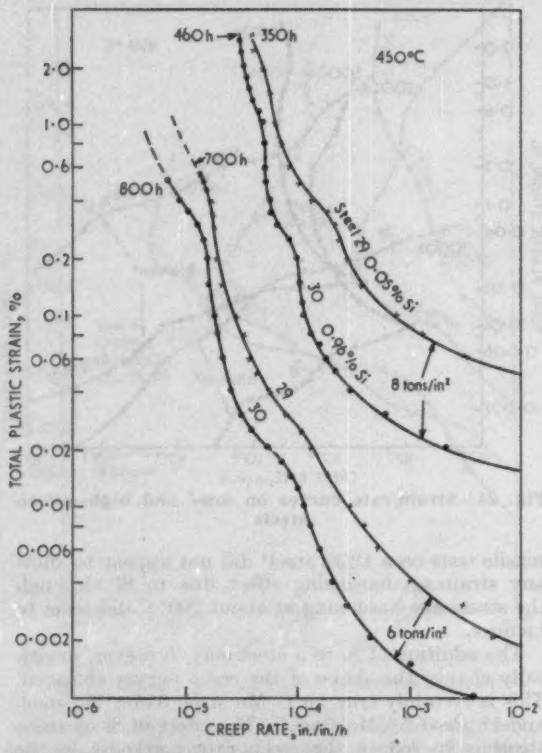


Fig. 25—Strain/rate curves on Al-killed low- and high-silicon steels

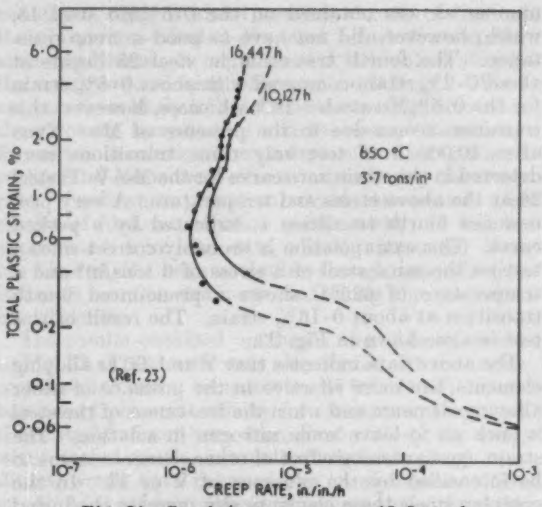


Fig. 26—Strain/rate curves on 18–8 steel

to that of an aluminium-killed C–Mn steel in Fig. 9. From the results in Fig. 36 it can be concluded that silicon has a small solution-hardening effect. Comparison of Figs. 24 and 25, however, leads to the conclusion that Si has a powerful influence on strain-age hardening when active nitrogen is present. A possible explanation is that some silicon nitride exists as a fine dispersion before testing, thus increasing the initial creep resistance, and that more silicon nitride precipitates in the dislocations during straining, instead of iron nitride. At a later stage, however, silicon nitride spheroidizes and becomes ineffective, so that at high strains the creep rate is fast and approximates to that of aluminium-killed steel. Some support for the presence of silicon nitride is given by the work of Turkdogan and Ignatowicz[22] who found that silicon nitride ($Si_3N_4$) exists in high-silicon steels.

It is obvious that much work remains to be done to obtain a full explanation of the effect of Si on the creep properties of steel. The above information, however, suffices to prove that Si does modify the strain-age-hardening behaviour of steel. The effect of this element is therefore not an exception to the theory which has been outlined.

### Effect of Other Alloying Elements

Some work has been done to show that tungsten influences the creep properties in a manner similar to Mo. This is to be expected in view of the similarity of behaviour in high-temperature tensile tests.[4] Copper is also known to improve the creep properties of steel. However, the data available on these and other

## Table VII
### TYPICAL COMPOSITIONS OF AUSTENITIC ALLOYS

| Reference | Alloy | Treatment | Composition, % | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | Si | Mn | Ni | Cr | Mo | W | Ti | Nb | Co | Cu | Al |
| 36 | 18–18 | Solution treated | ... | ... | ... | 0·18 | 8 | ... | ... | ... | ... | ... | ... | ... |
| 31, 37 | 18–9–1 | 1050° C A.C. | 0·11 | 0·50 | 0·41 | 9·5 | 17·8 | ... | ... | ... | 1·22 | ... | ... | ... |
| 37 | 18–12–1* | 1050° C A.C. | 0·12 | 0·78 | 1·41 | 12·1 | 18·5 | ... | ... | ... | 1·33 | ... | ... | ... |
| 31, 37 | 326 | 1250° C W.Q. + Aged | 0·25 | ... | 3·0 | 17 | 17 | 2·5 | ... | ... | 1·8 | 7 | ... | ... |
| 31, 37 | 327 | 1250° C W.Q. + Aged | 0·20 | ... | ... | 17 | 17 | 3·0 | ... | 0·8 | ... | 7 | 3 | ... |
| 39, 40, 41 | G18B | 1320° C A.C. | 0·4 | 1·0 | 0·8 | 13 | 13 | 2·0 | 2·5 | ... | 3·0 | 10 | ... | ... |
| 25 | '80–20'* | 1225° C 3 h W.Q. | ... | ... | ... | (80) | (20) | ... | ... | 2·74 | ... | ... | ... | 0·31 |
| 42 | Nimonic 80A | 1080° C 8 h A.C. + 16 h 700° 3 | 0·1 max. | 1·0 max. | 1·0 max. | (75) | 20 | ... | ... | 2·3 | ... | 2·0 | ... | 1·0 |

* Actual analysis

less common alloying elements were insufficient to justify inclusion in this paper. One other element, namely boron, is worthy of mention. This element tends to combine with nitrogen, but it may also act as an interstitial element. There is some evidence in the literature that it may substantially improve the creep properties. The effect of this element is thus worthy of study to see if it results in additional transitions in creep rate.

### Austenitic Alloys

In the preceding part of this paper the evidence presented in support of the theory is confined to results on ferritic alloys, i.e. with body-centred-cubic lattice structures. It is well known that such alloys are particularly subject to strain-age-hardening effects because they are detectable at room temperature. Austenitic alloys, on the other hand, which have a face-centred-cubic structure and a high solubility for carbon and nitrogen, are not considered prone to such effects. The evidence of high-temperature tensile tests (Fig. 2) does, however, suggest that strain-age hardening at high temperatures is possible.

Very little systematic creep testing appears to have been carried out on simple austenitic alloys and the data available in the literature do not show creep curves from which creep rates can be measured. It was thus impossible to build up a logical chain of evidence similar to that given for the ferritic steels. Data were, however, available on the alloys detailed in Table VII.

Duplicate tests on a simple austenitic steel in the solution-treated condition (probably 1050° C W.Q.) have been reported by Cross and Lowther.[23] These tests, both of more than 10,000 h duration, were carried out at a stress of 8345 lb/in² (3·7 tons/in²) and a temperature of 1200° F (649° C). Creep-rate data were given in tabular form and the results have been plotted to give the strain/rate curves shown in Fig. 26. Since the initial deformation on loading was 0·06%, the unknown part of the curves must take the form indicated roughly by the pecked curves.

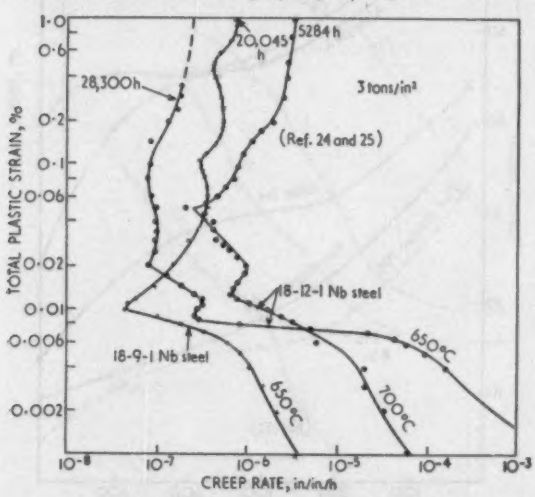


**Fig. 27—Strain/rate curves on 18–9–1 and 18–12–1 niobium steels**

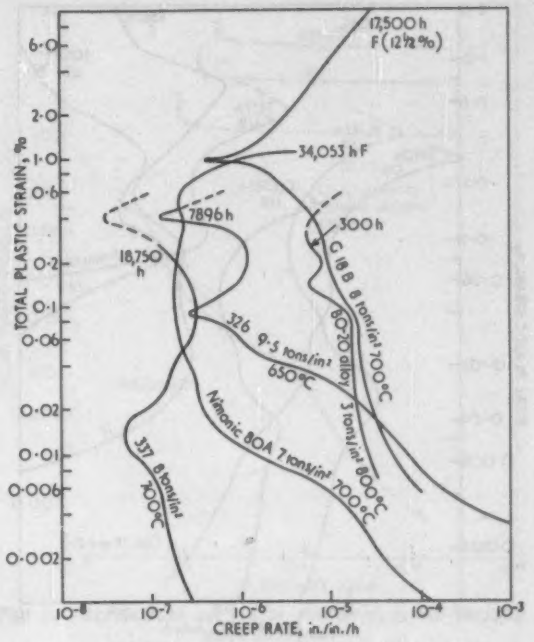


**Fig. 28—Strain/rate curves on various complex alloys**

Although the creep rates of the two tests vary somewhat in the early stages, they later approximate quite closely. It will be noted that two transitions in creep rate are obtained in each test. One of these is probably related to the precipitation of chromium carbide during straining. In view of the few remaining possibilities the other transition may be due to precipitation of iron carbide. If this is correct it should be the first transition which refers to this constituent.

Kirkby and Sykes[24, 25] carried out creep tests on an 18–9–1 Nb steel. From the result of a 20,000-h test at a stress of 3 tons/in² and a temperature of 650° C the strain/rate curves shown in Fig. 27 were calculated. Data on a similar steel of higher Ni content were also obtained.[25] The results of tests at a stress of 3 tons/in² and temperatures of 650° and 700° C are also shown in Fig. 27. It is interesting to note that whereas the 18–8 steel (Fig. 26) shows two transitions in creep rate, the Nb steels show three. By tempering a test-piece even for 20,000 h at 650° C it is not to be expected that niobium carbide would precipitate.[26] On the other hand, since some strain hardening occurs during creep, the possibility of strain-induced precipitation of niobium carbide must be considered possible. However, such questions can hardly be finalized by ordinary techniques. Electron-microscope studies of creep specimens may, however, give a definite answer to many of these problems.

The Nb steels have a substantially better creep resistance than the 18–8 steel. It would appear, therefore, that Nb in austenitic steel has an effect similar to V or Ti in ferritic steel.

Comparing the two tests on the 18–12–1 steel it is evident that, apart from the initial stages, the two curves are reasonably parallel. From a family of such

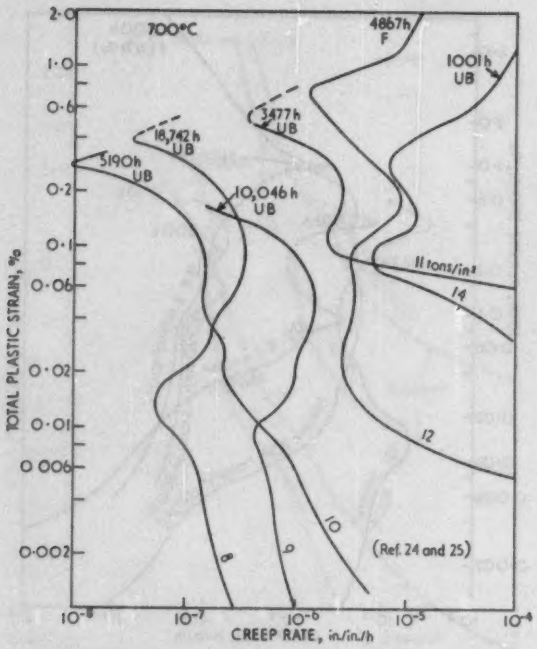


**Fig. 29—Strain/rate curves at various stresses on alloy 327**

curves, therefore, it should be possible to predict the strain/rate curve for a lower temperature from the results at higher temperature in a manner similar to that shown for ordinary steel. These 18–12–1 steels were tested in the solution-treated condition so that the time held at temperature before loading the test may cause some precipitation. At 700° C more precipitation is liable to occur before testing than at 650° C, with the result that the initial creep resistance is better in this test than in that at 650° C. Many such inversions have been reported in the literature. Probably most of these result from the same cause.

Kirkby and Sykes[24, 25] have also carried out long-duration creep tests on two complex austenitic alloys 326 and 327. Oliver and Harris[27–29] have tested an alloy now well known as G18B, and Pfeil *et al.*[30] have improved on the 80–20 Ni–Cr type of alloy by the addition of Ti and Al. Detailed information on Nimonic 80A was also received.[31] Strain/rate curves of individual tests on these alloys are shown in Fig. 28, from which it is obvious that one or more transitions in creep rate occur in each case.

An examination of the results on one of these alloys in more detail is interesting. Figure 29 shows strain/rate curves on alloy 337 at 6 different stresses, the temperature of testing being 700° C. The curves for stresses of 8, 9, and 12 tons/in² are reasonably symmetrical and show at least three transitions in creep rate. The curve for 14 tons/in² is distorted compared with the others, but this may be because of recovery processes resulting from the higher stress. The curves for 10 and 11 tons/in² appear to be displaced, though transitions can still be detected. These results emphasize the great experimental difficulties associated with the testing of such complex alloys. The strain/rate method of presentation does, however, help to indicate which tests are out of line.

Three test results on G18B were available at a stress of 6 tons/in² and temperatures of 650°, 750°, and 850° C. One of these tests was of 65,746 h duration. The strain/rate curves indicate that at least two transitions in creep rate are obtained in each test and that these transitions occur at higher strain levels the higher the temperature of testing. Since these tests were reported in an earlier paper[24] dealing with rupture tests it is not necessary to reproduce the data here.

All the above materials can be considered as steels or at least iron-base alloys. Detailed information was also obtained[31] on one f.c.c. type of alloy, namely, Nimonic 80A, which has a Ni base, Fe being present only as an impurity. This alloy was solution-treated for 8 h at 1080° C, and air cooling was followed by an ageing treatment of 16 h at 700° C with a further air cooling. The tests were carried out at a temperature of 700° C using stresses of 16, 13, 10, 7, and 4 tons/in². The longest test (34,053 h) was at 7 tons/in². In each of the five tests, three transitions in creep rate were obtained. These results were also reproduced in the earlier paper[24] but the above statement serves to indicate that transitions in creep rate can be obtained in alloys other than steels.

It has been shown that transitions in creep rate are found on testing austenitic alloys, as was also the case for ferritic alloys. These transitions are clearly revealed by the strain/rate method of plotting. From a family of such curves it should be possible to predict the long-duration creep properties of austenitic alloys as with ordinary steels.[5] The particular constituent

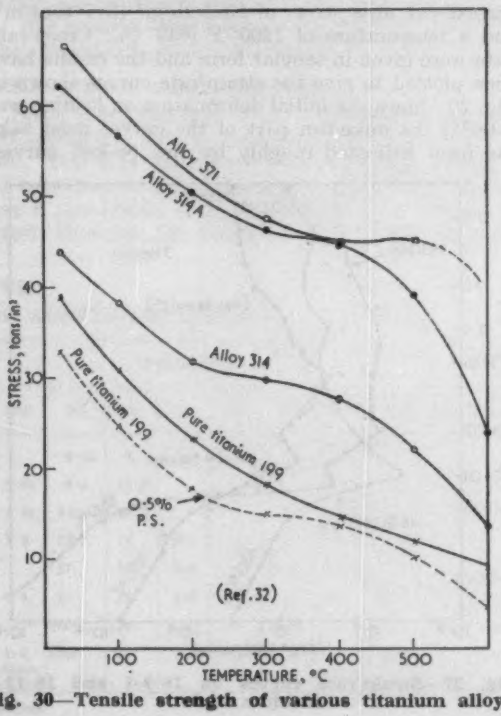


**Fig. 30—Tensile strength of various titanium alloys**

responsible for each transition is unknown in most cases. Tests carried out on simple austenitic alloys with single alloy additions would be very informative.

### Titanium and Titanium Alloys

The vast majority of commercial alloys can be classed under one of three main lattice structure types. Alloys of the two cubic types of structure have already been shown to give transitions in creep curves which can be correlated with strain ageing or strain-induced precipitation. All that remains, therefore, is to show that alloys with a hexagonal close-packed structure behave in a similar manner. One of the most important metals of this type at the present time is Ti, and attention, therefore, will be confined to the results of creep tests on Ti and Ti alloys. Summarized data on 1000-h tests have been published by I.C.I.[32] Full details of these tests have been obtained.[33] The alloys tested were as follows:

| Alloy | Type |
|---|---|
| 199 | Commercially pure, but not highest purity |
| 314 | Low-aluminium–manganese alloy |
| 314A | High-aluminium–manganese alloy |
| 371 | Al–Sn alloy of high creep resistance |

The first three of these alloys were tested in the form of hot-rolled bar, but alloy 371 was heat-treated, being quenched from 1100° C followed by annealing for 1 h at 800° C.

High-temperature tensile results have also been given for these steels.[32] These results are summarized in Fig. 30. It will be noted that strain-age hardening seems to occur in the three alloys, resulting in a retardation of the rate of fall of tensile strength with increasing temperature. Alloy 371 shows a slight maximum in tensile strength at about 500° C. The commercially pure Ti does not appear to strain-age harden as judged by the tensile strength, but the curve of stress to give 0·5% strain does show such an effect. This difference indicates that at high strains rapid recovery or recrystallization takes place. Similar effects should show up during creep testing of the commercially pure Ti at high temperatures.

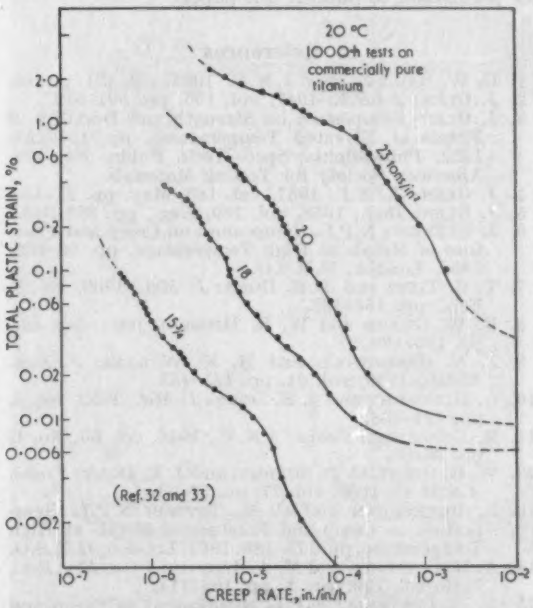


**Fig. 31—Strain/rate curves at room temperature on commercially pure titanium**

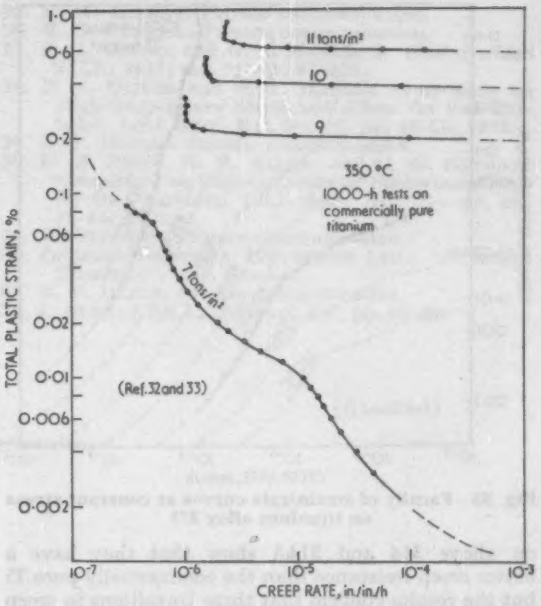


**Fig. 32—Strain/rate curves at 350° C on commercially pure titanium**

As shown in Fig. 30 strain ageing is not pronounced in commercially pure Ti and occurs at a higher temperature than in steel. It is therefore not altogether surprising to find that Ti creeps quite extensively at room temperature, as is shown by the strain/rate curves of tests on commercially pure Ti in Fig. 31. In each of the four tests, three transitions in creep rate were obtained. The second of these is not very pronounced but since it occurs in all four tests it cannot be attributed to experimental error. The types of precipitate responsible for these ageing effects are more or less unknown but it is significant that in Ti considerable amounts of three impurity alloying elements may be present in interstitial solution. These, of course, are nitrogen, carbon, and oxygen.

The commercially pure Ti was also tested at 350° C giving the strain/rate curves shown in Fig. 32. The curves for the test at 7 tons/in² show two transitions in creep rate. The third, if detectable at this temperature, must take place at a very low strain value. On testing at a stress of 9 tons/in² or higher, simple curves of the pure-metal type are obtained. The curves show no transitions in creep rate because recovery takes place so rapidly that ageing cannot occur. If the test at 7 tons/in² had been continued for a longer time it is possible that recovery would set in at a higher strain value, causing anomalies in the shape of the creep curve. As already noted, the occurrence of rapid recovery during creep was to be expected in view of the shape of the tensile curve obtained (Fig. 30).

Strain/rate curves for room-temperature creep tests

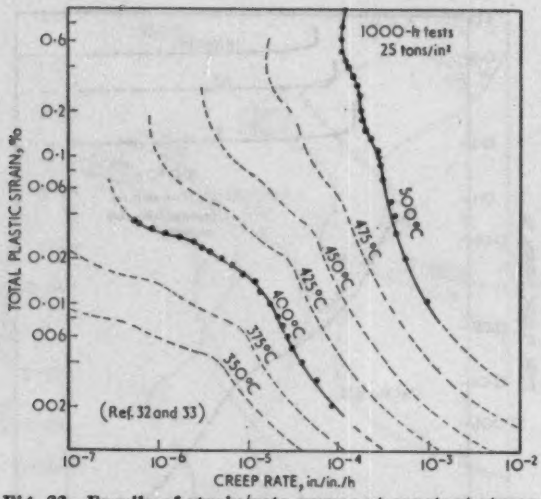


**Fig. 33—Family of strain/rate curves at constant stress on titanium alloy 371**

on alloys 314 and 314A show that they have a better creep resistance than the commercially pure Ti but the results confirm that three transitions in creep rate are obtained in room-temperature tests. There is no need therefore to reproduce the curves.

Only two test results were available to indicate the trend in tests at constant stress and varying temperature. These tests were carried out on alloy 371 at temperatures of 400° and 500° C using a stress of 25 tons/in². The results are shown in Fig. 33. There seems no reason to doubt that if more tests had been carried out at, say, 25° C intervals, then a family of curves would have been obtained similar to that obtained with C–Mn steel. Pecked curves have been added to the diagram to show the probable results of such tests.

## SUMMARY AND CONCLUSIONS

(1) A simple functional relationship appears to fit the creep of pure metals or simple solid solutions with or without a stable precipitate, since the only submicroscopical change during creep testing is strain hardening.

(2) In most commercial alloys other structural changes occur during creep testing and evidence is given to show that these changes are of the strain-age-hardening or the strain-induced precipitation type.

(3) These changes manifest themselves by the occurrence of transitions in creep rate. A transition can be described as a sudden deceleration of creep rate over an interval of time. A transition can occur at any stage in a creep test.

(4) A simple theory was developed to explain the occurrence of transitions in creep rate and to show the effect of the stress and temperature of testing on these transitions. This theory makes use of log strain/log creep-rate curves (strain/rate curves) to show up the transitions more clearly.

(5) Data are given to show the effects of N, C, Mn, Cr, Mo, V, Ti, and Si on the creep resistance of steel.

(6) In face-centred-cubic type alloys transitions in creep rate also occur as evidenced by data on various austenitic steels and other alloys.

(7) Similarly in alloys of the close-packed hexagonal type transitions can occur. This was shown by creep tests on commercially pure Ti and Ti alloys.

(8) The effect of heat-treatment was not considered in detail, but examples are given showing the effect of normalizing temperature and of tempering on the results obtained.

(9) In conclusion, it should be emphasized that although the paper throws some new light on the phenomenon of creep and on the effect of alloying elements it also shows up the many deficiencies in our present knowledge of the subject. In particular very little is known about the effect of combinations of alloying elements and of heat-treatment on the long-duration properties of alloys. It would also be very helpful if the exact mechanism of strain ageing could be established. Perhaps a series of electron micrographs taken during the progress of a creep test might lead to a solution of the vexed question as to whether or not precipitates do exist in the dislocations or whether the term 'atmosphere' would be more appropriate.

## Acknowledgments

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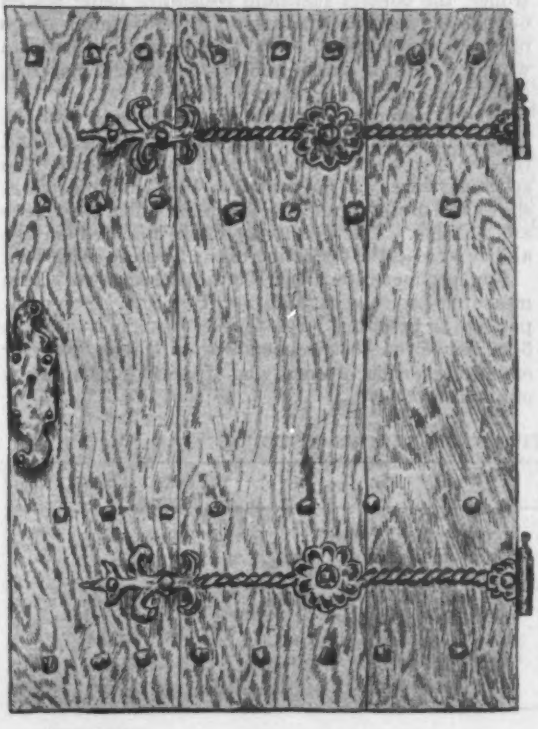
He also gratefully acknowledges the criticisms of his colleagues and the encouragement given by Mr. W. Barr, Director and Chief Metallurgist, Colvilles Ltd. He must also thank him and his fellow directors for permission to publish this paper.

## References

1. R. W. Bailey: *Proc. I.M.E.*, 1935, vol. 131, p. 145.
2. J. Glen: *J.I.S.I.*, 1947, vol. 155, pp. 501–512.
3. J. Glen: Symposium on Strength and Ductility of Metals at Elevated Temperatures, pp. 184–221: 1952, Philadelphia, Spec. Tech. Publn. No. 128, American Society for Testing Materials.
4. J. Glen: *J.I.S.I.*, 1957, vol. 186, May, pp. 21–48.
5. J. Glen: *Ibid.*, 1958, vol. 189, Aug., pp. 333–343.
6. J. E. Dorn: N.P.L. Symposium on Creep and Fracture of Metals at High Temperature, pp. 89–132: 1954, London, H.M.S.O.
7. T. E. Tietz and J. E. Dorn: *J. Met.*, 1956, vol. 8, Feb., pp. 156–162.
8. R. W. Guard and W. R. Hibberd jun.: *Loc. cit.*, pp. 195–199.
9. J. N. Greenwood and H. K. Worner: *J. Inst. Metals*, 1939, vol. 64, pp. 135–158.
10. O. D. Sherby and J. E. Dorn: *J. Met.*, 1953, vol. 5, pp. 324–338.
11. M. Gensamer: *Trans. A.S.M.*, 1946, vol. 36, No. 1, pp. 36–60.
12. W. H. Giedt, O. D. Sherby, and J. E. Dorn: *Trans. A.S.M.E.*, 1955, vol. 77, pp. 57–63.
13. L. Rotherham and C. R. Tottle: N.P.L. Symposium on Creep and Fracture of Metals at High Temperature, pp. 175–188: 1954, London, H.M.S.O.
14. A. H. Cottrell and M. A. Jaswon: *Proc. Roy. Soc.*, 1949, vol. 199, ser. A, pp. 104–114.
15. A. H. Cottrell: N.P.L. Symposium on Creep and Fracture of Metals at High Temperature, pp. 141–152: 1954, London, H.M.S.O.

16. G. Wood and J. R. Rait: *Iron Coal Trades Rev.*, 1949, vol. 158, pp. 221–228.
17. R. W. Ridley: *Proc. I.M.E.*, 1954, vol. 168, pp. 470–482.
18. A. B. McIntosh: Private communication.
19. J. Glen: *J.I.S.I.*, 1955, vol. 179, pp. 320–336.
20. E. L. Robinson: *Mech. Eng.*, 1943, vol. 65, pp. 166–168.
21. J. Glen: *J.I.S.I.*, 1948, vol. 158, pp. 37–80.
22. E. T. Turkdogan and S. Ignatowicz: *Ibid.*, 1957, vol. 185, Feb., pp. 200–206.
23. H. C. Cross and J. G. Lowther: *Proc. A.S.T.M.*, 1937, vol. 37, Pt. 1, pp. 178–186.
*Ibid.*, 1938, vol. 38, Pt. 1, pp. 121–129.
24. H. W. Kirkby and C. Sykes: Symposium on High-temperature Steels and Alloys for Gas Turbines, *I.S.I. Spec. Rep.* No. 43, pp. 95–106: 1952.
25. H. W. Kirkby: Private communication.
26. M. G. Gemmill: Private communication.
27. D. A. Oliver and G. T. Harris: *J. West Scotland I.S.I.*, 1947, vol. 54, pp. 97–119.
28. D. A. Oliver and G. T. Harris: Symposium on High-temperature Steels and Alloys for Gas Turbines, *I.S.I. Spec. Rep.* No. 43, pp. 46–59: 1952.
29. G. T. Harris: Private communication.
30. L. B. Pfeil, N. P. Allen, and C. G. Conway: Symposium on High-temperature Steels and Alloys for Gas Turbines, *I.S.I. Spec. Rep.* No. 43, pp. 37–45: 1952.
31. W. Stephen: Private communication.
32. Imperial Chemical Industries Ltd.: "Wrought Titanium," 1955, London.
33. N. P. Inglis: Private communication.
34. J. Glen: *J.I.S.I.*, 1958, vol. 190, pp. 30–39.

# *Sussex Ecclesiastical Ironwork — III*



Our illustration shows the door of the aumbry at the parish church of St. Nicholas at Icklesham, Sussex.

Icklesham lies on the edge of the area round Battle where iron was worked from prehistoric times until this century. Straker in his "Wealden Iron" (1931) records the presence of a Roman bloomery in the parish, and charcoal blast-furnaces were in operation in the surrounding area during the heyday of the Wealden industry.

The parish church is a beautiful and interesting structure, built on a hill. It was founded before the Norman Conquest, and traces of the earliest building are still visible. Most of the present fabric dates from the 12th and 13th centuries.

The aumbry, a small cupboard 25 in. × 19 in. let into the north wall of the sanctuary and used for storing the chalice and other sacramental vessels, probably dates from the early 14th century, when the chancel was extended with the addition of the present sanctuary. It is protected by the stout oak door shown in the illustration, by Miss Helena Hall. This is decorated with a series of roughly pyramidal headed studs arranged in four rows, two delicate wrought-iron rides, and an ornamental keyplate. The rides in particular are of very excellent workmanship. The age of this ironwork is not known, but from its style it would appear to be of some antiquity.

# Recent Developments in Creep Testing by the Cantilever Bending Method

*By G. T. Harris, M.A., F.Inst.P., F.I.M., H. C. Child, B.Sc., A.I.M., A. B. Collier, and C. F. West*

SYNOPSIS

Cantilever creep units of high strain sensitivity are described. These are capable of carrying out tests at temperatures up to 1200° C, at stresses of from 50 lb/in² to 50 tons/in² with a sensitivity of strain measurement of from 1 to 3 × $10^{-6}$.

Several suitable applications of these units are exemplified. These include alloy development where the stress for low creep strains is the criterion, tests on precision castings, 'micro-specimens,' unmachinable materials, sheet, tests above 1000° C, and tests *in vacuo* or in inert atmospheres.

It is shown that satisfactory correlation of cantilever creep data with tensile data is possible. 1569

SOME YEARS AGO, a creep unit was developed for high-temperature testing by a cantilever bending method.[1] Originally the method was chosen because it permitted the use of a very simple specimen which could be precision-cast or made by powder-metallurgical methods, but it was soon apparent that the method was suited to many other purposes, including testing at temperatures in the range 1000–1200° C.

As the test units began to be used for a wider variety of applications than the relatively crude sorting tests for which they were originally intended, it became necessary to improve the design and sensitivity. The design of the units now in use, the type of work they are carrying out, and a comparison of the cantilever results with tensile data are reported in the paper.

## DESCRIPTION OF EQUIPMENT

### Cantilever Creep Testing up to 950° C (Type 1 Units)

The original type of unit reported earlier[1] was of a very simple type. The specimen was stressed by a 12-in. beam and a carrier and slotted weights. The deflection of the beam relative to the frame of the unit was measured by a scale graduated in hundredths of an inch and attached to the beam. A razor-blade bolted to the frame acted as a reference point. The new units have attached to the frame a micrometer head which is adjusted until electrical contact is made between the end of the micrometer and an insulated needle attached to the end of the loading beam, which has been reduced to 8 in. long.

Contact is indicated by a neon bulb circuit which has proved very sensitive, allowing reproducible readings to ± 0·0001 in. to be made. Neon bulbs used at 230 V have proved more sensitive for this purpose than 6-V filament bulbs.

Figure 1 shows this Type 1 unit diagrammatically. A unit of this type is placed in each end of a Nichrome-wound resistance-heated furnace having a tube size of 15 in. × 2 in. i.d. These furnaces are wound in two zones, which may be shunted to allow any temperature difference between the two units to be corrected. The temperature is controlled by means of a Prosser controller, the control platinum resistance being placed outside the furnace windings to give maximum usage of the furnace space. The Type 1 unit is made in wrought G.19, a strong and scale-resistant material, whose composition is given in Table I.

Several different specimen types are used with the Type 1 unit, depending on the stressing required and the strain to which the test has to be carried out. The specimen types are illustrated in Fig. 2, and Table II shows the useful stress and strain for which specimens are suitable. The sensitivity figure is based on the ability to read the deflection of the beam to 0·0001 in.

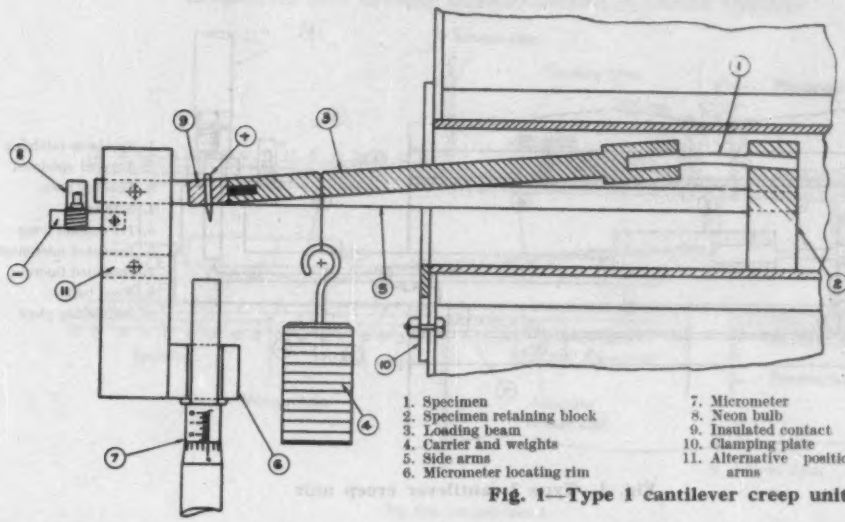
For specimens 104*A* and 108 the sensitivity of strain measurement is very high, i.e. 1 × $10^{-6}$. For comparison, a precision large tensile creep unit using a 5-in. gauge length specimen with a Marten's mirror extensometer has a sensitivity of strain measurement of about 2 × $10^{-6}$.

Manuscript received on 15th April, 1958.

Mr. Harris is Research Director, Mr. Child is Research Manager, and Mr. Collier and Mr. West are members of the Research and Development Department of William Jessop and Sons, Ltd.

**Table I—NOMINAL COMPOSITIONS OF ALLOYS USED, %**

| Quality | C | Mn | Si | Ni | Cr | W | V | Mo | Co | Fe | Ti | Cu | Al | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G.19 | 0·4 | 0·8 | 1·0 | 13·0 | 20·0 | 2·5 | | | 10·0 | | | | | 3·0 |
| Nimonic 80 | 0·1 max. | 1·0 max. | 1·0 max. | Remainder | 19·0 | | | | 2·0 max. | 5·0 max. | 2·2 | | 1·2 | |
| W.7 | 0·15 | 1·2 | 1·0 | 75·0 | 17·0 | | | 1·0 | | Remainder | | | 1·0 | 1·0 |
| G.42B | 0·25 | | 0·30 | 15·0 | 20·0 | 3·0 | | 3·0 | 25·0 | | 1·0 | | | |
| G.32 | 0·30 | | 0·50 | 12·5 | 19·0 | | 2·8 | 2·0 | 45·0 | | | | | 1·30 |
| G.39 | 0·55 | 1·0 | 0·8 | 65·0 | 20·0 | 3·0 | | 3·0 | | | | | | 3·0 |



1. Specimen
2. Specimen retaining block
3. Loading beam
4. Carrier and weights
5. Side arms
6. Micrometer locating rim
7. Micrometer
8. Neon bulb
9. Insulated contact
10. Clamping plate
11. Alternative position for side arms

**Fig. 1—Type 1 cantilever creep unit**

**Cantilever Creep Testing above 950° C (Type 1*a* and Type 2 Units)**

At testing temperatures above 950° C, several new problems arise. Where the materials to be tested are sufficiently strong to require test loads of at least 0·5 tons/in², a modification of Type 1 units has proved satisfactory. To improve the strength and scale resistance of these Type 1*a* units, and to permit use up to 1200° C, they are made in cast G.39, whose composition is given in Table I.

The minimum stress which can be applied is about 0·5 tons/in², even when the larger specimen No. 113 is used.

Where appreciably lower stresses are required, Type 2 units must be used. In this case the whole stress is applied by a 3-in. loading beam. Unlike Type 1 units, carriers and weights are never used to increase the stress above that applied by the loading beam.

The Type 2 unit is shown diagrammatically in Fig. 3. These units are heated in platinum–rhodium wound furnaces of the same size and type as used for the lower-temperature tests, the ancillary equipment also being similar.

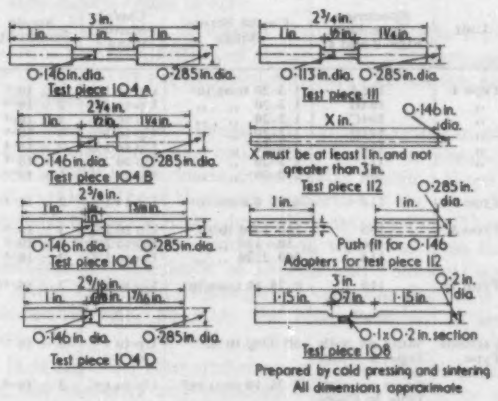



**Fig. 2—Specimens for Type 1 unit**

The use of a short loading beam, apart from lowering the stress, enables the whole beam to be inside the furnace, which permits the furnace end to be more efficiently sealed than with Type 1 units. This is particularly important at these higher testing temperatures. The Type 2 unit is made in either G.39 or a very scale-resistant material W.7 (*see* Table I).

The strain of the specimen, i.e. the deflection of the loading beam, is transmitted by a 1 : 1 lever to a point outside the furnace, where it can be conveniently measured by a Vernier micrometer. This, as in the case of Type 1 units, can be read to ± 0·0001 in., using a neon bulb to indicate contact.

As soon as the unit, with the specimen and loading beam, has been placed in the furnace, the deflection ($d_1$) of the beam is determined and is due to elastic bending of the specimen at room temperature ($\epsilon_{20}$). To prevent creep during heating up, the strain-reading lever is left in contact with the loading beam; no deformation of the knife edges has resulted. When the specimen has attained the desired temperature the micrometer head is withdrawn momentarily and then a second deflection reading ($d_2$) is taken. The deflection is now due to elastic bending of the beam at the test temperature ($\epsilon_t$) and to any plastic strain ($\epsilon_p$) which has occurred on loading: $d_2 - d_1 = \epsilon_p + \epsilon_t - \epsilon_{20}$. As the applied stress is normally low for these high-temperature tests, $\epsilon_{20}$ and $\epsilon_t$ are both small and $\epsilon_{20}$ cannot exceed $1/E$, i.e. approximately $1 \times 10^{-4}$. Hence for all practical purposes $\epsilon_{20}$ and $\epsilon_t$ can be ignored and the difference between the first and second deflection of the beam is due to plastic strain on loading, i.e. $d_2 - d_1 = \epsilon_p$.

The choice of specimen again depends on the test conditions (*see* Fig. 4 and Table II).

For stresses from 50–150 lb/in², the loading beam is machined integrally with the specimen (Type 106), but where the applied stress is in the range 150–1000 lb/in², specimen 105 is used with a separate loading beam. For higher stresses of 500–2240 lb/in², specimen 114 is used.

Owing to the short length of the loading beam, it

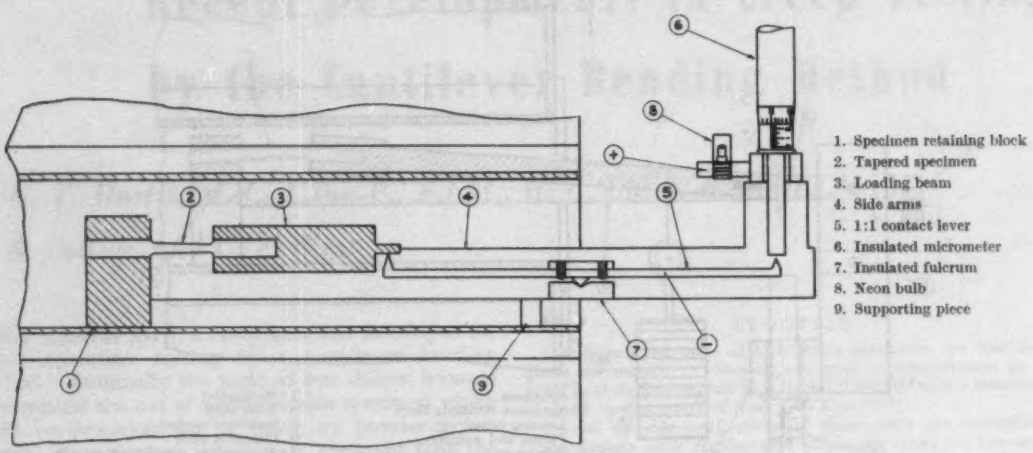



**Fig. 3—Type 2 cantilever creep unit**

has been found necessary to use tapered specimens for Type 2 units to ensure uniformity of stressing along the gauge length. The strain sensitivity of Type 2 units with these specimens is shown in Table II. Although somewhat less ($2–3 \times 10^{-6}$) than the Type 1 units, it is still comparable with precision tensile creep units.

### Testing of Sheet and Strip (Type 2a Units)

Where thin-gauge sheet or strip has to be tested, a 3-in. loading beam of the type used in Type 2 units must be used to give suitable stressing. The deflection at the end of this beam is again transmitted to a point outside the furnace by a 1 : 1 lever arm and measured by a Vernier micrometer. The loading beam and the specimen retaining block both have a slit to accommodate the specimen instead of the usual 0·3-in. dia. hole. The unit may be made from either wrought G.19 for temperatures up to 950° C, or cast G.39 for higher temperatures.

A specimen (No. 115) suitable for 16-s.w.g. sheet is shown in Fig. 4. As indicated in Table II, this specimen can be stressed in the range ¼–10 tons/in² with a strain sensitivity of $2 \times 10^{-6}$.

Owing to the adaptability of these units, different specimen types to cover other gauges of sheet or stress ranges can be readily devised.

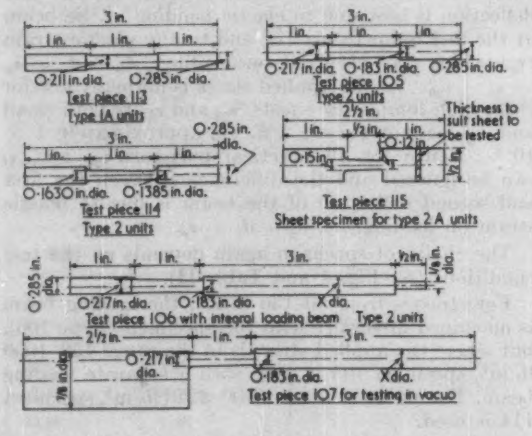



**Fig. 4—Specimens for Type 1*a*, 2, and 2*a* units**

### Cantilever Creep Testing *in vacuo* (Type 3 Unit)

A modified Type 2 unit that can be operated *in vacuo* is shown schematically in Fig. 5. This may use any of the cylindrical or sheet specimens normally used with Type 2 or 2*a* units. The unit is pumped by a small oil diffusion pump and rotary mechanical pump; the usual procedure is to outgas at the test temperature to a pressure of 1–5 microns and then to carry out the test at a small positive pressure of argon. Contact of the micrometer stem and the strain-measuring lever is indicated by a neon bulb circuit.

Alternatively, specimen type 107 (Fig. 4) comprising an integral block, gauge length, and loading beam can

## Table II

### TYPES OF SPECIMEN AND THEIR USES

| Unit | Specimen Type (see Figs. 2 and 4) | Useful Stress Range | Useful Strain Range | Strain Sensitivity |
|---|---|---|---|---|
| Type 1 | 104*A* | 1·3–20 tons/in² | Up to 1% | $1 \times 10^{-6}$ |
| ,, | 104*B* | 1·3–20 ,, ,, | Up to 2% | $2 \times 10^{-6}$ |
| ,, | 104*C* | 1·3–20 ,, ,, | Up to 4% | $4 \times 10^{-6}$ |
| ,, | 104*D* | 1·3–20 ,, ,, | Up to 8% | $8 \times 10^{-6}$ |
| ,, | 111 | 2·6–56 ,, ,, | Up to 1% | $2 \times 10^{-6}$ |
| ,, | 112 | 1·3–20 ,, ,, | Up to 2% | $2 \times 10^{-6}$ |
| ,, | 108 | 2·0–30 ,, ,, | Up to 1% | $1 \times 10^{-6}$ |
| Type 1a | 113 | 0·5– 6 tons/in² | Up to 1% | $2 \times 10^{-6}$ |
| Type 2 | 105 | 150–1000 lb/in² | Up to 2% | $3 \times 10^{-6}$ |
| | 106 | 50– 150 ,, ,, | Up to 2% | $3 \times 10^{-6}$ |
| | 114 | 500–2240 ,, ,, | Up to 1% | $2 \times 10^{-6}$ |
| Type 2a | 115 e.g. 16 s.w.g. sheet | 0·25–10 tons/in² | Up to 1% | $2 \times 10^{-6}$ |
| Vacuum Type | Same as with Type 2 Units | 50–2240 lb/in² | Up to 1% or 2% | $3 \times 10^{-6}$ |
| | Same as with Type 2a Units | 0·25–10 tons/in² | Up to 1% | $3 \times 10^{-6}$ |

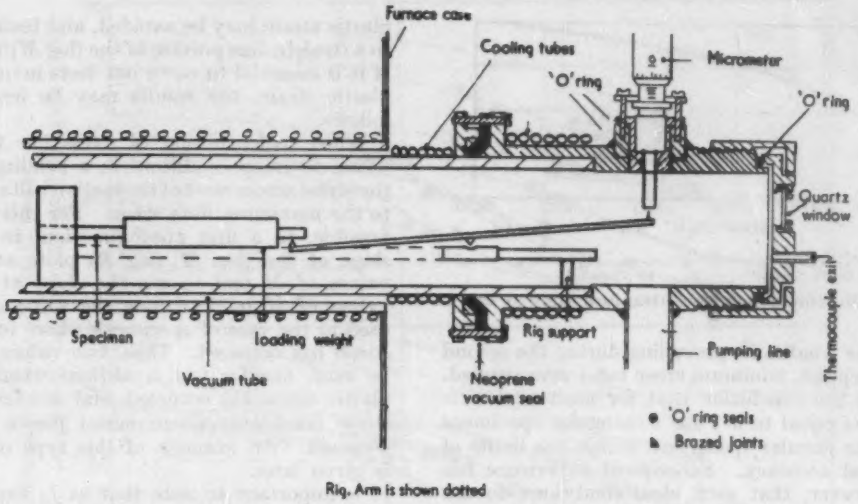



**Fig. 5—Diagram of vacuum or gaseous atmosphere creep unit**

be used. The specimen is tested in a suitable horizontal tube furnace *in vacuo* or in inert gas and, after the desired test period, it is withdrawn from the furnace and the deflection of the beam is measured.

## INTERPRETATION OF RESULTS

When a cantilever creep specimen is loaded up to the elastic limit, the maximum fibre stress ($f_E$) may be calculated from the conventional elastic theory of bending with the usual assumptions:

(1) Elastic modulus is the same in tension and compression, and stress is proportional to strain

(2) Transverse sections of the beam, plane before bending, remain plane after bending

(3) The beam bends to a circular arc of large radius compared to the transverse section of the beam

(4) The transverse section of the beam is symmetrical about an axis passing through the centroid of the section and parallel to the plane of bending

(5) The resultant thrust across a transverse section of the beam is zero.

If the specimen is loaded above the elastic limit, there is a redistribution of stress which is determined by the shape of the stress/strain curve in tension and compression.

To consider what stress distribution occurs in the specimen under creep conditions, the same assumptions must first be made as in elastic bending theory, but in this instance the creep properties of the material must be the same in tension as in compression. There is little experimental evidence on which to base this postulate but the work of Tapsell and Johnson[2] and of Sully, Cale, and Willoughby[3] suggests that it is a reasonable one, at least for creep strains of less than 1%.

It is assumed that under creep conditions in bending the stress in any particular fibre is the same as that which would cause the same creep rate in a tension or compression test. Using this assumption, Tapsell and Johnson[2] showed that for a material whose tensile creep properties could be expressed by the law

$$f = AR^n \quad \ldots\ldots(1)$$

where $f$ = stress, $R$ = creep rate, $A$ and $n$ are constants for the material at the test temperature, the actual maximum fibre stress ($f_A$) in a rectangular specimen bending under creep conditions would be given by the equation

$$f_A = \frac{n+2}{3} \cdot f_E \quad \ldots\ldots(2)$$

For circular specimens, the relationship between $f_A$ and $f_E$ has been shown[1] to be

$$f_A = f_E \frac{\sqrt{\pi}}{\times 8\left(\frac{\Gamma\frac{(n+2)}{2}}{\Gamma\frac{(n+3)}{2}} - \frac{\Gamma\frac{(n+4)}{2}}{\Gamma\frac{(n+5)}{2}}\right)} \quad \ldots\ldots(3)$$

If a test is carried out at a stress $f_E$, calculated from elastic theory, it behaves similarly to a tensile test carried out at stress $f_A$, and hence it is important to know the ratio $f_A/f_E$, which is denoted as $K$, the 'cantilever creep parameter'. Equations (2) and (3) relate $K$ to $n$, the creep exponent for rectangular and circular specimens respectively.

The problem of correlating bending creep data and tensile data is therefore to determine $n$ for the appropriate material and test conditions. Where $n$ is a constant, close correlation between bending and tensile results is possible, and even if $n$ varies with test conditions, it is possible in most circumstances to obtain a suitable average value for $n$, and hence for $K$.

The creep exponent $n$ is the slope of the log-stress/log-creep-rate plots for tensile data, and Tapsell and Johnson[2] showed that for lead at room temperature $n$ was substantially independent of time, and hence $f_A$ was constant during creep tests.

In the earlier paper,[1] the value of $K$ was derived from the creep exponent $n$ found by tensile creep tests,

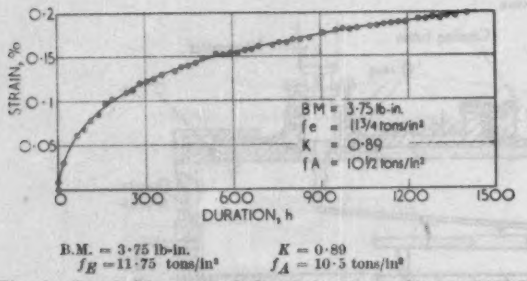



**Fig. 6—Strain/time graph for a titanium alloy at 400° C**

and only the conditions prevailing during the second stage of creep (i.e. minimum creep rate) were studied. This led to the conclusion that for most austenitic steels $K$ was equal to 0·7 for rectangular specimens and 0·63 for circular specimens, within the limits of experimental accuracy. Subsequent experience has shown, however, that such ideal conditions do not always hold for steels and other alloys.

For example, when steels are tested in the temperature range 400–600° C, where transient creep is relatively more pronounced than quasi-viscous creep, the slope of the log-stress/log-creep-rate plots for tension tests tend to increase with time, i.e. $n$ increases with time and so does the cantilever creep parameter $K$. It is necessary, therefore, to determine the creep exponent $n$ for the material and test conditions in question before the results of cantilever tests can be interpreted.

If a series of cantilever creep tests are carried out at one temperature using different bending moments ($M$), the creep exponent $n$ may be determined, Tapsell[4] having indicated that $n$ is the slope of (log $M$)/(log $R$) plot for cantilever tests, owing to the proportionality which exists between $M$, $f_E$, and $f_A$.

In practice the following procedure is adopted:

(1) A series of cantilever creep tests is carried out at different bending moments ($M$) at the desired temperature

(2) From the resulting strain/time graphs, a series of (log $M$)/(log $R$) plots are obtained where $R$ is the instantaneous creep rate at any time ($t$).

The types of results obtained fall into three classes.

(*a*) The (log $M$)/(log $R$) plots are straight lines whose slope ($n$) is independent of time. Under these conditions the maximum fibre stress, $f_A = K.f_E$, is constant.

(*b*) The (log $M$)/(log $R$) plots are straight lines whose slope ($n$) tends to increase with time. In this instance, which is typical of materials under transient creep conditions, the maximum fibre stress is not constant with time. In most cases the change in stress does not exceed 10–15%, and for practical purposes it is satisfactory to take an average value for $n$ and hence an average value for the maximum fibre stress, $f_A$.

(*c*) The (log $M$)/(log $R$) plots are best represented by two straight lines. If the range of bending moments $M$ studied has been sufficiently wide to include tests with initial plastic strain, the (log $M$)/(log $R$) plots generally show a change of slope. For many purposes test conditions involving initial plastic strain may be avoided, and testing confined to a straight-line portion of the (log $M$)/(log $R$) plot. If it is essential to carry out tests involving initial plastic strain, the results may be interpreted as follows.

When redistribution of stress has taken place owing to creep conditions in a bending specimen, the stress across most of the section will approximate to the maximum fibre stress. For this reason it is possible, to a first approximation, to ignore the slope of the (log $M$)/(log $R$) plots at the lower values of $M$ and to use the slope at the higher values of $M$ to determine the value of $K$, to be used in the case of specimens where initial plastic strain has occurred. Thus, two values of $K$ must be used, one for test conditions where no initial plastic strain has occurred, and one for the higher stress conditions where initial plastic strain has occurred. An example of this type of procedure is given later.

It is important to note that as $f_A$ can only vary between 0·59 $f_E$ and $f_E$, a completely arbitrary value of 0·8 $f_E$ for $f_A$ would be correct to within ± 25%, even in exceptional cases. In practice, the values of $n$ derived by the techniques described enable $f_A$ to be assessed more accurately, and only in extreme cases would the error be as great as ± 15%; more often it is less than ± 10%.

## APPLICATIONS OF CANTILEVER CREEP TESTING

To illustrate the use which is being made of this equipment examples of actual tests will be quoted.

### Alloy Development with Particular Reference to Tests at Low Total Strain

The major use being made of this equipment is the development of heat-resisting alloys to give, say, 0·1% plastic strain in 300 h. Figure 6 is a typical strain/time graph for an experimental titanium alloy at 400° C, using test piece No. 111 with an applied bending moment of 3·75 lb-in. The high sensitivity of Type 1 units, even using a ½-in. gauge-length specimen, is shown by the low degree of scatter.

Figure 7 gives the (log $M$)/(log $R$) plots at times of from 30 to 300 h, derived from a series of tests such as that shown in Fig. 6 with $M$ varying from 2·22 to 13·1 lb-in. It is difficult to measure instantaneous creep rates with a high degree of accuracy, but it is considered that a series of nearly parallel lines fit these

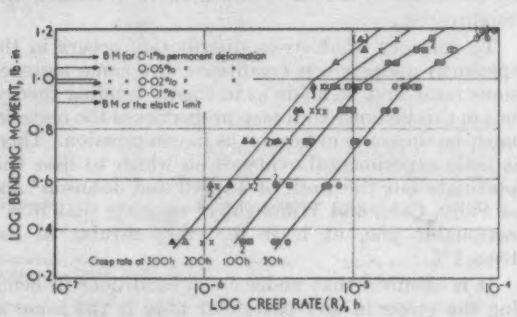



**Fig. 7—(Log $M$)/(log $R$) plots at various times for a titanium alloy**

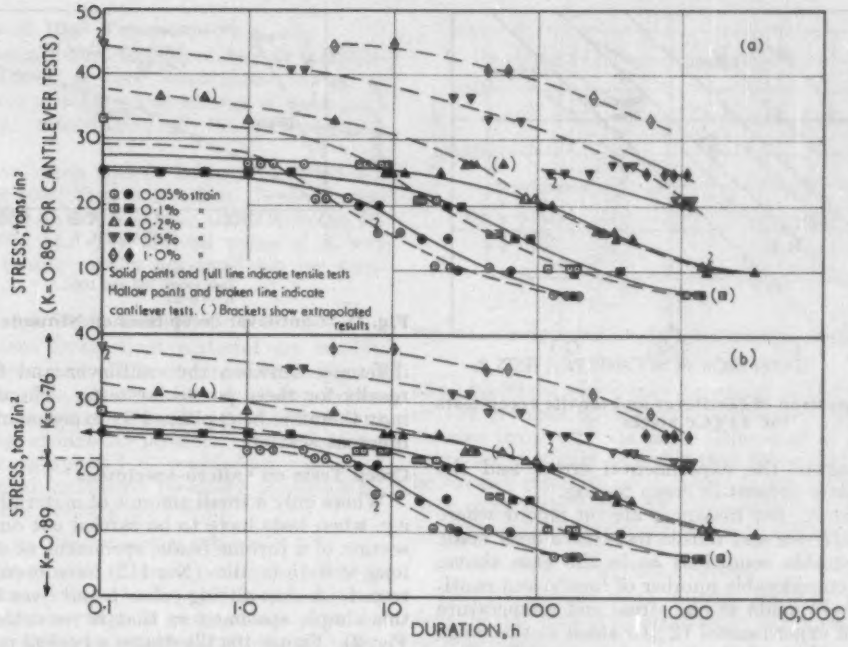



**Fig. 8—Comparison of cantilever and tensile creep results for a titanium alloy at 400° C**

points satisfactorily, except for the tests at the higher bending moments. For the main portion of the curve, the slope $n$ is 0·74, and this does not change from 30 to 300 h. The cantilever creep factor $K$ may be taken as constant at 0·89, and so the actual maximum fibre stresses in these tests are effectively constant from 30 to 300 h and equal to 0·89 of the elastically calculated stress.

The results of these cantilever tests and the corresponding precision tensile creep tests are shown in Fig. 8*a*, using the conventional stress/log-time plots. The agreement between the two test methods is reasonable between 6 and 20 tons/in², but above this the cantilever and tensile results diverge. The point of divergence coincides with the change in slope of the bending-moment/instantaneous-creep-rate plots shown in Fig. 7.

At the higher bending moments, the lower slope of the (log $M$)/(log $R$) plots results in a lower value of $K$ of 0·76. Using the procedure described above, Fig. 8*b* has been derived, which utilizes the value of 0·89 for $K$ below the knee of the (log $M$)/(log $R$) plot, and 0·76 for tests above this.

A comparison of the tensile and cantilever creep stresses for the same strain/time criterion is made in Table III, using both the results shown in Fig. 8*a* with a single value for $K$, and the results shown in Fig. 8*b* with two values for $K$.

There is good agreement between the cantilever and tensile tests, particularly when the more complicated method of treatment is used. It is important to remember that the creep strength determined by the tensile method is probably not more accurate than

## Table III
### COMPARISON OF TENSILE AND CANTILEVER CREEP STRESSES

| Tensile Creep Stress, tons/in² | Cantilever Creep Stress for Same Strain/Time Criterion, tons/in² | | | | | Error of Cantilever Stress, % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0·05% | 0·1% | 0·2% | 0·5% | 1·0% | 0·05% | 0·1% | 0·2% | 0·5% | 1·0% |
| 7 | 6½ | 6½ | ... | ... | ... | − 7 | − 7 | ... | ... | ... |
| 10 | 8½ | 9 | 10 | ... | ... | −12½ | −10 | 0 | ... | ... |
| 15 | 12½ | 13½ | 14½ | ... | ... | −15 | −10 | − 3 | ... | ... |
| 20 | 17½ | 18½ | 20 | 21 | ... | −12½ | − 7½ | 0 | + 5 | ... |
| 25 (Fig. 8*a*) | 29 | 31½ | 30 | 30½ | 31½ | +16 | +27 | +20 | +22 | +26 |
| 25 (Fig. 8*b*) | 24½ | 25½ | 25½ | 24½ | 26½ | − 2 | + 3 | + 2 | − 1 | + 7 |

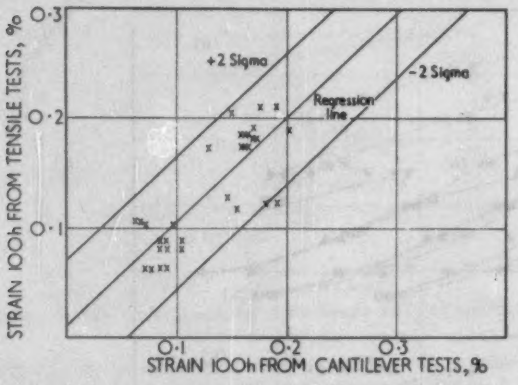
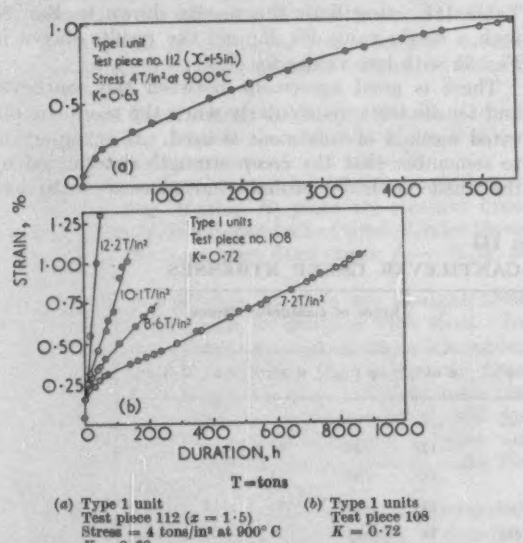



**Fig. 9—Comparison of cantilever and tensile creep tests for 12%Cr steels**

$\pm 5\%$, owing to the experimental errors and the inherent scatter present in creep testing.

Unfortunately, few instances are on record where as many cantilever and tensile tests have been made under comparable conditions as in the case above. However, a considerable number of tensile and cantilever tests were made at one stress and temperature on a series of experimental 12%Cr steels in the range 400–600° C. Most of the tests were carried out at 32 tons/in² at 500° C. The percentage strain at 100 h is plotted in Fig. 9 for both the tensile and the cantilever tests.

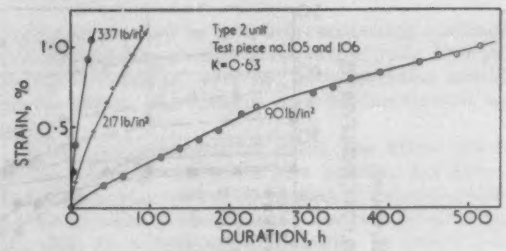
The regression line of $Y$ upon $X$ and the standard deviation for this set of results has been calculated. The regression line is indicated in Fig. 9, which also shows the 95% ($\pm$ 2 sigma) confidence limits; the standard deviation was found to be 0·03%. The results for only one steel lie outside the 95% confidence limits, indicating that there is no significant




(*a*) Type 1 unit
Test piece 112 ($x = 1·5$)
Stress = 4 tons/in² at 900° C
$K = 0·63$

(*b*) Type 1 units
Test piece 108
$K = 0·72$

**Fig. 10—Cantilever creep tests on (*a*) a specimen from the aerofoil section of a G.42 gas-turbine blade, (*b*) a sintered TiC-base alloy at 850° C**




Type 2 unit
Test pieces 105 and 106
$K = 0·63$

**Fig. 11—Cantilever creep tests on Nimonic 80 at 1200° C**

difference between the cantilever and tensile creep results for these particular tests. The discrepancies may therefore be explained by experimental error and inherent scatter.

### Creep Tests on 'Micro-specimens'

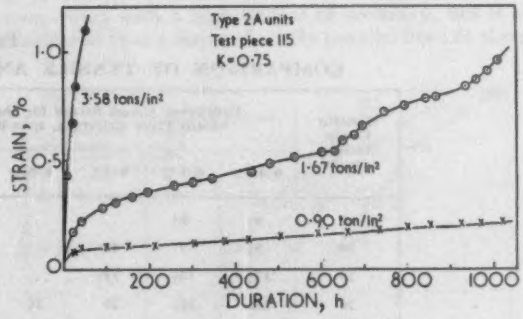
Where only a small amount of material is available, e.g. when tests have to be carried out on the aerofoil section of a turbine blade, specimens as small as 1 in. long × 0·15 in. dia. (No. 112) have been successfully tested. A close-fitting collar is put over both ends of this simple specimen so that it resembles 104*B* (*see* Fig. 2). Figure 10*a* illustrates a typical result on such a specimen machined from the aerofoil section of a gas-turbine blade and tested at 4 tons/in² at 900° C ($K = 0·63$).

The high strain sensitivity for a 'micro-test' is apparent.

### Creep Tests on Unmachinable Materials

When material is unmachinable and the part is fabricated by precision casting or powder metallurgy, the simplicity of form of the cantilever specimen is useful. Specimen 108 is easily cold-pressed to shape from metal powders, while the cylindrical form of specimen 104*B*, for example, lends itself to hot-pressing in an axial direction.

Figure 10*b* gives the strain/time graphs for a series of tests on a sintered titanium-carbide-base material at 850° C, using test piece 108. As these specimens were rectangular in section, $K$ was calculated from the equation $K = (n + 2)/3$ and found to be 0·72.




Type 2*a* units
Test piece 115
$K = 0·75$

**Fig. 12—Cantilever creep tests at 850° C on 16-s.w.g. G.19 sheet**

### Data Collection at High Temperatures

The use of tensile creep extensometers at temperatures above 1000° C is very troublesome, owing to clamping problems, scaling and seizing of bolts used for assembling, deformation of the extensometer limbs, etc.

The cantilever creep test is, however, carried out as easily above 1000° C as it is below. Some typical results at 1200° C on a nickel-base alloy, Nimonic 80, are given in Fig. 11. The derived value of $K$ was 0·63, but no tensile results are available for comparison.

### Data Collection on Sheet Specimens

Strip specimens from sheet material are readily tested in cantilever units. The results of some typical tests at 850° C on 16-s.w.g. sheet in a high-temperature alloy (G.19) are shown in Fig. 12, which shows that tests to low total strains are possible. The inflections in the strain/time graph at 1·67 tons/in² are associated with metallurgical instability (possibly recrystallization). The results indicate $K = 0{\cdot}75$.

### Data Collection on Precision-cast Alloys

A considerable amount of use is now being made of precision-cast materials for heat-resisting applications, such as nozzle guide vanes in gas turbines. As the large castings needed to produce a precision creep specimen would differ metallurgically from the smaller castings whose properties it is often desired to evaluate, the determination of creep data on precision-cast alloys can be carried out with advantage by the cantilever method.

### Tests *in vacuo* and Protective Atmosphere

There is occasionally interest in the creep properties of alloys at temperatures above those at which the alloys are stable in air. This demand arises from applications where the alloy is used in a protective atmosphere or under reducing conditions. For example, the cobalt-base alloy G.32 scales very severely at temperatures above 980° C, and so when some creep strength results were required at 1100° C, the tests were carried out in an atmosphere of argon. These results are shown in Fig. 13.

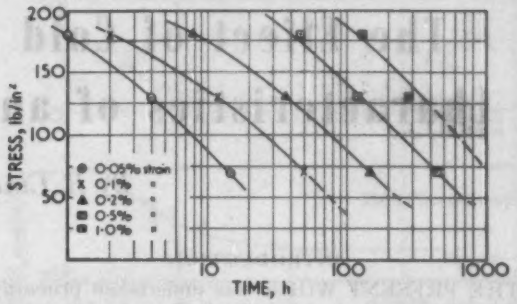



**Fig. 13—Creep tests on G.32 material in static argon at 1100° C**

## DISCUSSION

The examples given of the use of cantilever creep testing have been chosen to illustrate the problems of interpretation and the versatility of the method. It has been the authors' experience that for austenitic alloys in the temperature range 650–1200° C, the interpretation is reasonably satisfactory, and the estimated value of $f_A$ is correct to within $\pm$ 10% and is constant within the limits of accuracy of the interpretation and the testing technique. At lower temperatures (300–600° C), where mainly ferritic alloys and titanium have been tested, the interpretation is more difficult owing to transient creep. The value of $f_A$ may not be constant with time, but for any specific criterion the average value of $f_A$ can be estimated to $\pm$ 10%.

In practice the use of the cantilever method has enabled large alloy development programmes to be successfully carried out and preliminary data to be obtained with a minimum of cost and experimental effort. The practical advantages are felt to outweigh any objections which may be raised to the technique on the grounds of difficulty of interpretation of the stresses involved. As more experience is gained in using the methods, it is felt that these problems will be further resolved, as in many instances paucity of data over wide ranges of stress and time has made accurate interpretation of the data difficult.

## CONCLUSIONS

The cantilever creep testing method has been developed so that high-sensitivity strain measurements may be made.

For many purposes there is an advantage in using cantilever creep testing instead of precision tensile creep testing, and these are summarized below:

(1) For alloy development, where the stress for low creep strains is the criterion, there is a saving in testing costs and material

(2) For creep tests on precision-cast alloys, specimen preparation is facilitated

(3) Creep tests on ' micro-specimens ' enable small components to be evaluated

(4) For creep tests on unmachinable materials (e.g. carbides made by powder metallurgy), specimen preparation is facilitated

(5) For creep tests above 1000° C, extensometry and shackle problems are overcome

(6) For creep tests on sheet material, extensometry and shackle problems are simplified

(7) For creep tests *in vacuo* or under inert atmosphere, simple inexpensive equipment may be used.

In addition to these advantages, the cantilever creep units are inexpensive and, as two units are used in each furnace, the cost of temperature control and recording equipment is reduced.

Where a comparison has been made between cantilever and tensile results, there is satisfactory agreement, the results being generally within $\pm$ 10%.

## Acknowledgment

The authors wish to express their thanks to Mr. D. Hodkin for his assistance and interest in the earlier experimental work.

## References

1. G. T. HARRIS and H. C. CHILD: *J.I.S.I.*, 1950, vol. 165, pp. 139–144.
2. H. J. TAPSELL and A. E. JOHNSON: *J. Inst. Metals*, 1935, vol. 57, p. 121.
3. A. H. SULLY, G. N. CALE, and G. WILLOUGHBY: *Nature*, 1948, vol. 162, p. 411.
4. H. J. TAPSELL: Private communication.

# The Effect of Cold Work on the Fatigue Characteristics of an Austenitic Alloy Steel

*By B. Cina, B.Sc., Ph.D.*

SYNOPSIS

The limited beneficial effect of static cold work on the fatigue limit in alternating stress has been found to be due to the operation in the latter of a Bauschinger effect, evidence for which was provided from hardness measurements, X-ray diffraction and metallographic examination, and by carrying out fatigue tests both in direct alternating, and pulsating tensile stress. A much greater benefit from the cold work was obtained for pulsating tensile than for alternating stress. Fatigue cracks formed much earlier in alternating than in pulsating tensile stress. There was a suggestion that for alternating stress the formation and propagation of a crack were governed by the same mechanism which was dependent on the alternating character of the stress. A critical amount of static cold work was required before a fatigue failure was obtained in pulsating tension, while a critical amount of dynamic cold work was similarly required for alternating stress. Light tempering after static cold work failed to raise the fatigue limit in alternating stress. 1524

## INTRODUCTION

THE PRESENT WORK was undertaken primarily to explain the limited beneficial effect of cold work on the fatigue limit, as measured in reversed stressing, of an austenitic alloy steel. Relatively little work has been done on the effect of cold work on fatigue strength. An increase in fatigue limit with cold work has been reported for plain carbon steels,[1, 2, 3] an unstable and a stable austenitic alloy steel,[1] non-ferrous metals,[4, 5] and a titanium alloy.[6] The increase in fatigue limit for the plain carbon steels has been attributed to cold strengthening and surface compressive stresses resulting from static stretching,[1] although it is difficult to see why residual surface tensile stresses were not also present. Cazaud[2] attributed the increase in fatigue limit to work hardening resulting from cold drawing, but this would not explain the limited increase observed. The increase for the unstable austenitic 18%Cr–8%Ni alloy steel[1] was possibly due in part to the formation of martensite as a result of the cold work. The results for the stable austenitic 15%Cr–28%Ni alloy steel[1] were less certain, no definite increase being observed up to 18% stretching, but one was observed after 27% stretching. This aspect of austenite stability and fatigue strength has since been investigated more fully.[7] In none of the above references was any attempt made to explain the magnitude of the increase in fatigue limit relative to the increase in static tensile properties observed as a result of static cold work.

## EXPERIMENTAL WORK

### Materials Used

The work was carried out mainly on an austenitic alloy steel* supplied as ¾-in. dia. hot-rolled bar from two casts of the analyses given in Table I.

This material may be considered as a modified form of Hadfields 13%Mn steel, in that it contains only about one half of the latter's carbon and manganese content, but this is compensated for to some extent by about 8·5%Ni and 4%Cr. N.M.C. solidifies as austenite and undergoes no phase change down to −196° C, i.e. its $M_s$ point is below −196° C. However, the austenite could be induced to transform to ferrite by cold work in simple tension applied at −196° C or −78° C, although the amount formed at these temperatures was less than 5% since it could not be detected by X-ray diffraction. This ferrite was detected by a strong hand magnet. No transformation could be induced by cold work at R.T., i.e. the $M_d$ point† of the $\gamma \rightarrow \alpha$ transformation was below R.T. Fatigue tests carried out at R.T. could, therefore, be considered as being done on a stable austenitic alloy steel.

Treatment of the alloy for ½ h at 1050° C ensured the virtually complete solution of all carbide particles and resulted in complete recrystallization and softening of the material. Air cooling of ¾-in. dia. bar section from 1050° C, as was the standard prior treatment for all work to be described, resulted in a fine discontinuous precipitate of chromium carbide at the grain boundaries similar to that illustrated in Fig. 11. Since all the fatigue failures in the material were transcrystalline, the grain-boundary precipitate was not considered to have had any deleterious effect.

Like Hadfields 13%Mn steel, N.M.C. has a very high work-hardening capacity. Table II shows the mechanical properties of N.M.C., (*a*) as-softened, air cooled from 1050° C, and (*b–e*) as 1050°C A.C. + cold-worked 5, 10, 20, and 30% in tension at R.T. respectively.

Cold work markedly raised the proof stresses but not the limit of proportionality which, if anything, decreased initially with cold work.

### Details of Fatigue Tests

Most of the fatigue tests were carried out on Haigh machines operating at 6000 cycles/min. Tests were carried out both in reversed direct stress (zero mean stress) and in pulsating tension. For the latter, an alternating stress of $\pm S$ tons/in² was superimposed on a static stress of $+ S$ tons/in², giving a working stress range of 0–2$S$ tons/in², i.e. the static stress was always half the maximum. The test-pieces used had a gauge length of ½ in. × approx. 0·178 in.,

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*Hereafter referred to as N.M.C.

† $M_d$ is the maximum temperature below which transformation to martensite can be induced by plastic deformation. $M_d$ is always higher than $M_s$.

**Table I**
**ANALYSES OF MATERIALS USED**

| Cast No. | C | Si | Mn | S | P | Cr | Ni | N |
|---|---|---|---|---|---|---|---|---|
| 69190 | 0·63 | 0·41 | 7·45 | 0·008 | 0·034 | 4·00 | 3·35 | 0·015 |
| 87165 | 0·62 | 0·35 | 7·32 | 0·005 | 0·026 | 3·86 | 3·55 | 0·021 |

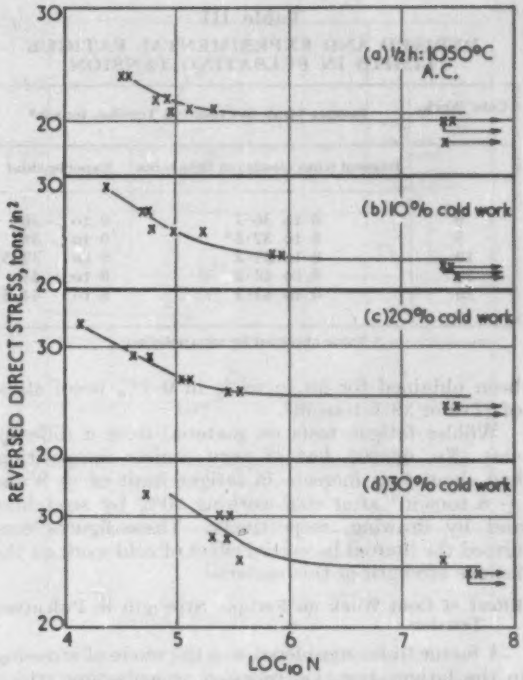
0·160 in., or 0·150 in. dia., smaller diameters having to be used for the higher stresses because of the limited load-carrying capacity of the machines used. After machining, all test-pieces were mechanically abraded with emery paper as far as 1M grade and then electropolished for 5 min, as described elsewhere,[8] the electropolishing removing about 0·003 in. from the diameter of the gauge length. In contrast to the effect on Wöhler fatigue test-pieces of this alloy steel,[8] electropolished Haigh test-pieces gave the same fatigue limit as those mechanically abraded as far as 000 emery paper.

Heat-treatment was carried out prior to machining. Cold-worked test-pieces were machined from the gauge lengths of tensile test-pieces which had been stretched slowly by the appropriate amount (5, 10, 20, or 30%) at R.T. It was possible to stretch softened material more than 30% without necking. $S/N$ curves were determined, most of the tests being done in duplicate. The fatigue limit was based on a test remaining unbroken for $25 \times 10^6$ cycles. Attention was paid more to the actual fatigue limit than to the precise slope of the finite life portion of the $S/N$ curve. A few Wöhler fatigue tests were also carried out using samples of 0·250 in. minimum diameter prepared similarly to the Haigh test-pieces. These samples were fatigued at 2900 cycles/min, as described elsewhere.[8]

The fatigue experiments on this material followed several lines, namely:

(i) The effect of cold work on the fatigue properties
(ii) The effect of mode of fatigue stressing on fatigue properties, i.e. alternating tension-compression, and pulsating tension
(iii) The effect of cold work followed by light tempering on the fatigue properties
(iv) A study of hardness changes during fatigue testing*

* A summary of some of the results in this section was published in *Proc. Roy. Soc.*, 1957, A, vol. 242, pp. 196–197.




(*a–d*) Softened + 0, 10, 20, and 30% cold work, respectively

**Fig. 1—*S/N* curves for reversed direct stress for different prior treatments**

(v) and (vi) A study of structural changes as detected by X-ray diffraction and optical microscopy during fatigue testing
(vii) The possible role of creep in the pulsating-tension fatigue tests.

## RESULTS

### Effect of Cold Work on Fatigue Strength in Reversed Direct Stress

Figures 1*a–d* show the $S/N$ curves for cast 87165 cold-worked 0, 10, 20, and 30% in simple tension at R.T. and then fatigue-tested in reversed direct stress. There is no sharp knee in any of these curves. The effect of cold work on fatigue limit is shown in Fig. 2*a*. Fatigue limit increases with cold work up to 20%; no further increase was obtained at 30%, although there was some increase in finite fatigue life, i.e. an increase in fatigue limit of only $\pm$ 5 tons/in² had

**Table II**
**EFFECT OF COLD WORK ON THE MECHANICAL PROPERTIES OF N.M.C.**

| Prior Treatment | Cast 87165 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Limit of Proportionality, tons/in² | Proof Stress, tons/in² | | | | Maximum Stress, tons/in² | Elongation, % | Reduction in Area, % |
| | | 0·05% | 0·1% | 0·2% | 0·5% | | | |
| As softened | 14·6 | 20·7 | 21·3 | 21·75 | 22·6 | 52·0 | 89 | 72 |
| Cold-worked 5% | 8·3 | 29·4 | 31·0 | 31·9 | 31·9 | 53·6 | 75·5 | 70·5 |
| Cold-worked 10% | 7·9 | 32·9 | 38·5 | 39·1 | 39·1 | 56·5 | 65·5 | 68·5 |
| Cold-worked 20% | 10·9 | 36·5 | 45·0 | 49·7 | 49·7 | 61·5 | 55·5 | 65 |
| Cold-worked 30% | 21·7 | 53·3 | 59·6 | 60·4 | 60·4 | 68·0 | 43·5 | 64 |

**Table III**

**DERIVED AND EXPERIMENTAL FATIGUE LIMITS IN PULSATING TENSION**

| Cold Work, % | Fatigue Limit in Pulsating Tension, tons/in² | |
|---|---|---|
| | Derived from Goodman Diagrams | Experimental |
| 0 | 0 to 36·1 | 0 to > 26 |
| 5 | 0 to 37·5* | 0 to > 34 |
| 10 | 0 to 39·2 | 0 to 39·5 |
| 20 | 0 to 43·2 | 0 to 43 |
| 30 | 0 to 43·2 | 0 to 44·5 |

* Value obtained by interpolation

been obtained for an increase in 0·2% proof stress of 27·9 or 38·6 tons/in².

Wöhler fatigue tests on material from a different cast (No. 69190), but of very similar composition, had shown[8] an increase in fatigue limit of ± 9 and ± 8 tons/in² after cold-working 20% by stretching and by drawing, respectively. These figures confirmed the limited beneficial effect of cold work on the fatigue strength of this material.

### Effect of Cold Work on Fatigue Strength in Pulsating Tension

A factor to be considered was the mode of stressing in the fatigue test, i.e. reversed or pulsating stress. A Bauschinger effect was expected to operate in the former but not in the latter and to apply to both softened and cold-worked material, so that plastic deformation and, therefore, presumably also fatigue damage could possibly occur in material nominally strengthened by cold working.

In order to determine the importance of stress reversal on fatigue strength, a series of test-pieces cold-worked 0, 10, 20, and 30% was fatigue-tested in pulsating tension, the results being compared with the series tested in alternating tension-compression. The $S/N$ curves for the pulsating-tension tests are illustrated in Figs. 3*a*, *c*, *d*, and *e*. No fatigue failure could be obtained in pulsating tension for non-cold-worked material. Since the 0·2% proof stress of the latter was 21·75 tons/in², it meant that stresses very much greater than this could not be applied because these would simply have stretched the test-pieces. The effect of cold work on the fatigue limit in pulsating tension is shown in Fig. 2*b*. The fatigue limit in pulsating tension is considerably greater than that for tension-compression, but increases with cold work at only a slightly faster rate.

The inability of non-cold-worked material to develop a fatigue failure in pulsating tension prompted the question as to whether a minimum critical amount of cold work was so required. From Goodman diagrams (based on the true fracture stress) it was found that non-cold-worked material should have a fatigue limit in pulsating tension of 0–36·1 tons/in². As this value is 13·5 tons/in² above the 0·5% proof stress of the material, it implies that a fatigue limit in pulsating tension can never be obtained for softened material and that the material must be cold-worked to a 0·5% proof stress of at least this extent if a fatigue limit in pulsating tension is to

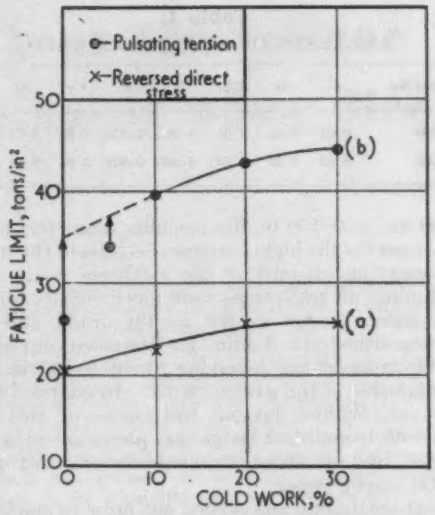
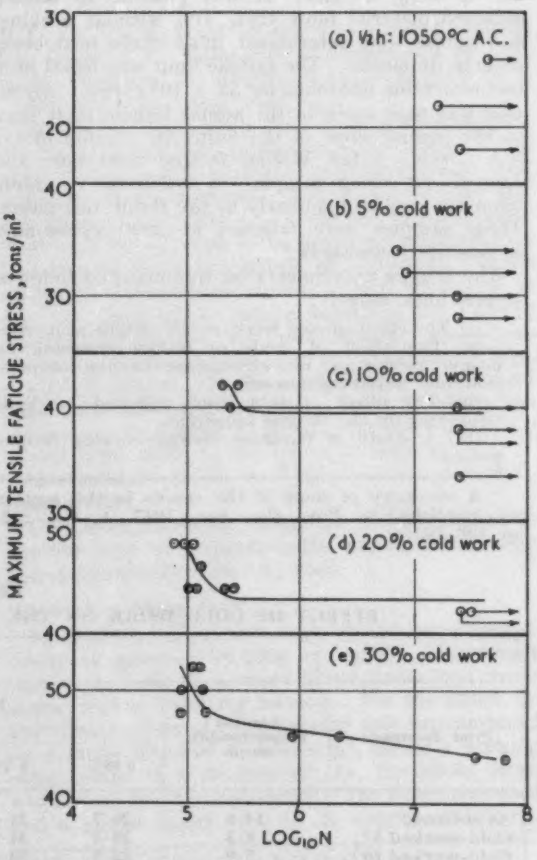



**Fig. 2—Relationship between fatigue limit and cold work**




(*a*–*e*) Softened + 0, 5, 10, 20, and 30% cold work, respectively

**Fig. 3—Fatigue lives and $S/N$ curves for pulsating tension for different prior treatments**

be obtained. A 0·5% proof stress of 36·1 tons/in² is obtained by 8·6% cold work as determined from the true-stress/true-strain diagram of the material. Therefore, material cold-worked less than 8·6% should not show a fatigue limit in pulsating tension, while that worked more than 8·6% might do so. It had already been determined that material cold-worked 10, 20, or 30% all showed such a fatigue limit in pulsating tension. Material cold-worked less than 8·6% should not show a fatigue limit, and testing of 5% cold-worked material showed this, in fact, to be the case, as shown in Fig. 3*b*.

As a further indication of the reliability of the Goodman diagrams, Table III shows the fatigue limits in pulsating tension derived from such diagrams, and the actual experimental values obtained for material cold-worked 0 to 30%. The agreement is considered to be good.

The inability to obtain a fatigue failure in pulsating tension is not found only in the austenitic alloy steel, N.M.C. A similar effect[9] has been found in a fully δ-ferritic 20%Cr iron tested after a prior softening treatment. However, when this material was cold-drawn 20%, fatigue failures and a fatigue limit *were* obtained in pulsating tension. With a heat-treatable 13%Cr steel, a fatigue limit was obtained in pulsating tension for material hardened and tempered to a tensile strength of 54 tons/in², without the necessity of cold working.[9]

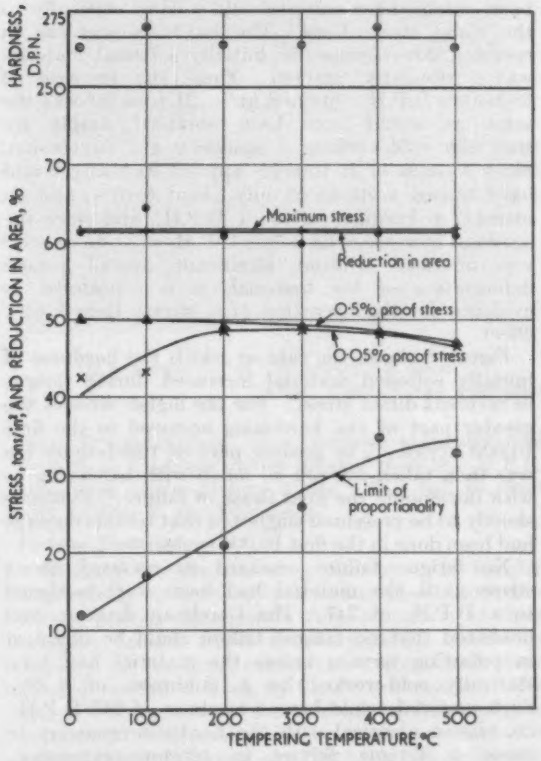
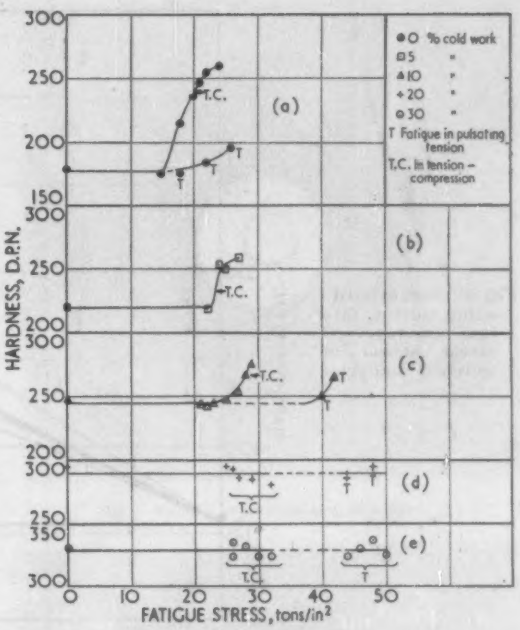



**Fig. 4—Effect of tempering for 1 h on the mechanical properties of cast 69190 cold-worked 20%**




(*a*–*e*) Softened + 0, 5, 10, 20, and 30% cold work, respectively

**Fig. 5—Effect of fatigue on hardness for different prior treatments**

### Effect of Cold Work followed by Tempering on Fatigue Strength

Although static cold work markedly raised the proof stresses, it had no such effect on the limit of proportionality. It was, therefore, possible that since plastic deformation could occur even in heavily cold-worked material at relatively low stresses, fatigue damage could also occur more readily and hence explain the relatively small gain in fatigue limit with cold work. If the limit of proportionality could be raised without appreciable softening of the material, an increased fatigue limit might be obtained. Test-pieces from cast 69190 stretched 20% at R.T. to a 0·5% proof stress of 50 tons/in² were tempered for one hour at 100°, 200°, 300°, 400°, and 500° C and their mechanical properties re-determined at R.T. The results are shown in Fig. 4.

Tempering has caused no significant change in D.P.H. or M.S. values, a slight drop in 0·5% proof stress, but a significant increase in limit of proportionality, the maximum effect being obtained after tempering at 400–500° C.

The Wöhler fatigue properties of this material cold-worked 20% in tension at R.T. had already been determined.[8] Accordingly, further material was cold-worked 20% at R.T., tempered for 1 or 24 h at 400° C and Wöhler fatigue tested. No change in fatigue limit was observed. Material cold-drawn instead of stretched 20% did show a slight increase in finite fatigue life as a result of stress relief, but no increase in fatigue limit.

X-ray back-reflection photographs showed line sharpening as a result of the tempering, confirming that the increase in limit of proportionality was due

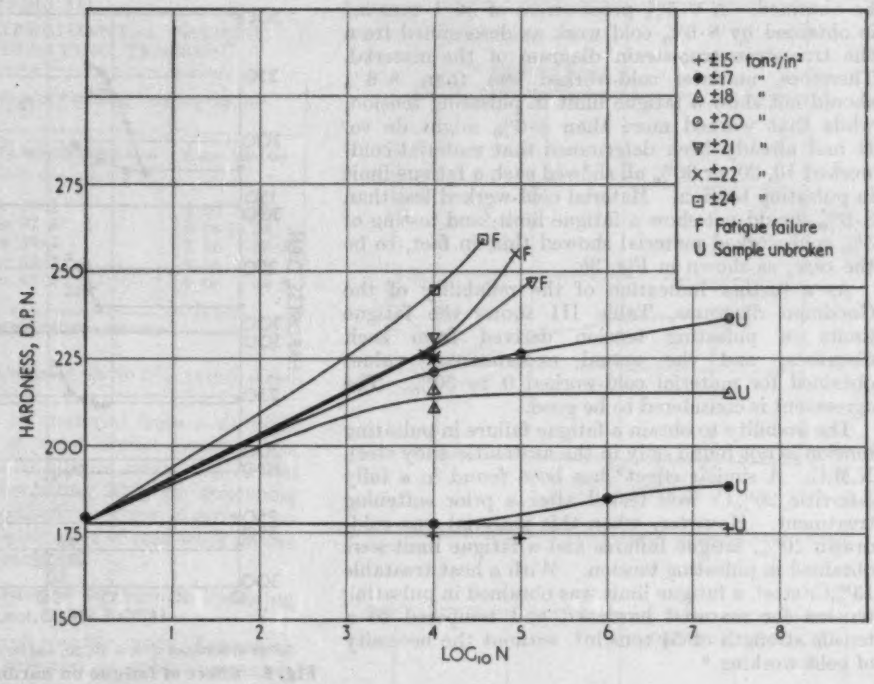



**Fig. 6—Rate of hardening during fatigue in reversed direct stress of softened material**

to stress relief. However, it was concluded that since the material was still in a cold-worked condition even after tempering at 500° C, as testified by the retention of its increased 0·5% proof stress and hardness values, it must still have contained residual micro-stresses. These would act together with the applied fatigue stress to give an effective fatigue stress greater than, and a fatigue limit lower than, the measured L.P. of the material.

## HARDNESS CHANGES AND 'DAMAGE' DURING FATIGUE TESTING

Since it has been found by others that initially softened material can work-harden, and that initially statically cold-worked materials can soften[10, 11, 12] during fatigue in reversed direct stress, it was of interest to know how N.M.C. behaved, especially as the marked operation of a Bauschinger effect was suspected for this mode of stressing.

Hardness measurements were made at four points on a transverse section taken about $\frac{1}{4}$ in. behind the fracture, or at the centre of Haigh test-pieces which were still unfractured after at least $25 \times 10^6$ cycles, and the results for such samples are shown in Figs. 5*a–e*. While hardening was believed to be uniform throughout the gauge length, the section was taken at $\frac{1}{8}$ in. behind the fracture to avoid the plastically deformed zone formed as the test-piece finally ruptured. Material cold-worked 0, 5, and 10% all showed significant hardening in reversed direct stress, while that cold-worked 20% or 30% did not. Where hardening occurred it increased with the applied stress. The corresponding hardness changes, if any, for pulsating tension were very much smaller and were of the same order as would have been obtained for material cold-worked statically to the same stress level. The hardness increase in reversed direct stress for initially softened material was particularly marked. Thus, the increase of 68 points D.P.H. obtained at $\pm$ 21 tons/in² was the same as would have been obtained simply by statically cold-working a sample 9·4% in tension. Since a stress of 21 tons/in² applied statically would have caused a strain of only about 0·07% and an increase in hardness of $< 1$ D.P.H., and since the hardness increase of 68 points D.P.H. at $\pm$ 21 tons/in² was obtained without significant overall plastic deformation of the material, it is considered as evidence for the operation of a strong Bauschinger effect.

Figure 6 shows the rate at which the hardness of initially softened material increased during fatigue in reversed direct stress. For the higher stresses the greater part of the hardening occurred in the first 10,000 cycles. The greater part of the fatigue life was then taken up, not so much with hardening as with developing the final cause of failure. Evidence shortly to be presented suggested that serious damage had been done in the first 10,000 cycles.

No fatigue failure occurred in reversed direct stress until the material had been work-hardened to a D.P.H. of 247. The Goodman diagram had predicted that no fatigue failure could be obtained in pulsating tension unless the material had been statically cold-worked by a minimum of 8·6%. Such material would have a hardness of 243 D.P.H., i.e. almost identical with the hardness necessary to cause a fatigue failure in tension-compression. However, this cannot be taken to mean that a hardness of about 243–247 D.P.H. will immediately

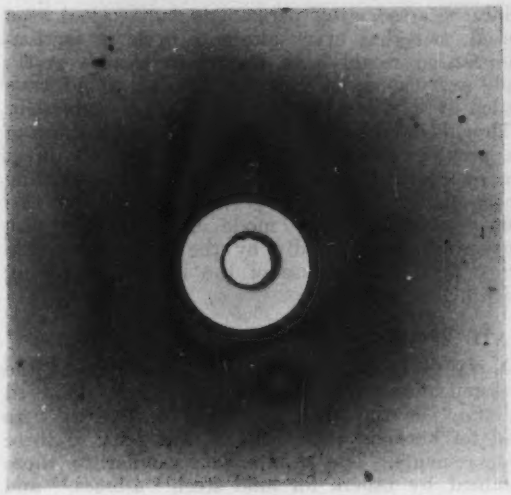


Fig. 7—Softened, ½ h/1050° C A.C.

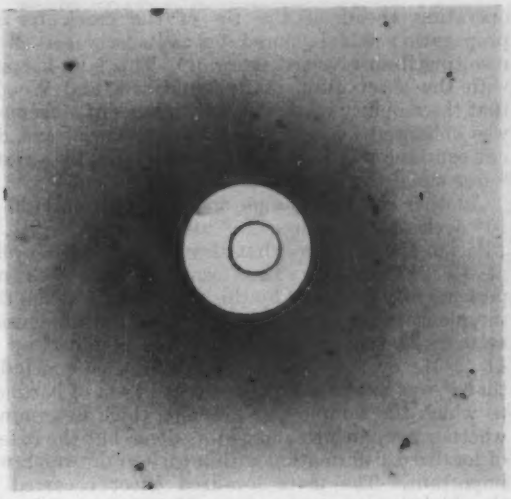


Fig. 8—Softened + $10^5$ cycles at ± 20 tons/in²

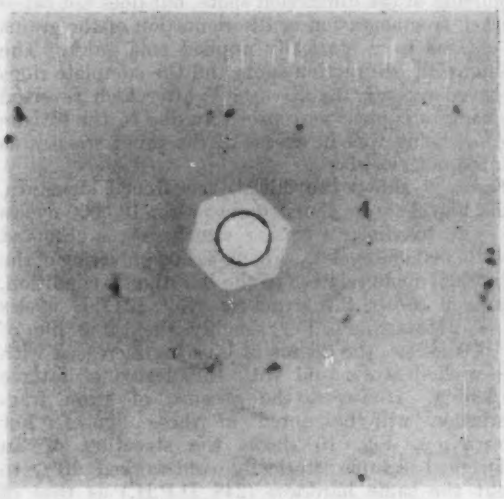


Fig. 9—Softened + $1{\cdot}34 \times 10^5$ cycles at ± 21 tons/in²

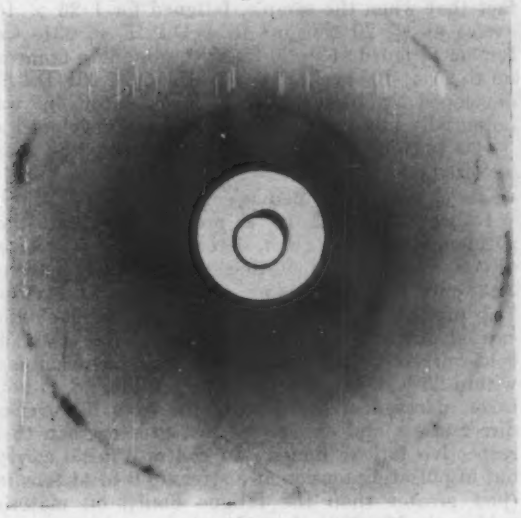


Fig. 10—Softened + 10% static cold work

**Figs. 7–10—X-ray diffraction back-reflection photographs**

cause fatigue failure, since samples statically cold worked to hardness values greater than 247 D.P.H. have even higher fatigue limits. This will be dealt with further in the Discussion.

**Fatigue Damage**

Softened samples run at ± 21 and ± 24 tons/in² respectively for 10,000 cycles, and stopped, showed no surface cracks. But static 20% extension of these samples caused small trans-crystalline cracks to appear, i.e. a fatigue-damaged region had been opened out into a crack by the 20% extension. The normal elongation to fracture of initially softened material is 89%, so that the crack was not due to the normal static failure of the material. Material cold-worked statically to the same hardness as that developed just prior to fatigue fracture would still have had an elongation at fracture of over 65%.

**Mode of Stressing and Crack Propagation**

Two interesting experiments are worth reporting here. If a softened sample was fatigued at ± 21 tons/in² for only 10,000 cycles to a D.P.H. of 231 and then unloaded, its life, if stressing had continued, would have been about 100,000–200,000 cycles even though such a sample was known to be permanently damaged after 10,000 cycles. When this sample, after 10,000 cycles at ± 21 tons/in², was then stressed in pulsating tension at 0 to 21 tons/in², it failed after 20,757,000 cycles, i.e. its life was increased about 100- to 200-fold by changing the mode of stressing. The tensile stress alone was less able to propagate the incipient crack than a reversed stress of the same magnitude. This might imply that the mechanism

operating ahead of the tip of the crack for its propagation was favoured by a Bauschinger effect resulting from reversed stressing. This is in keeping with the observation of Bullen, Head, and Wood[13] that the mobility of atoms on the planes of movement was enhanced by continuous stress reversal and did not continue when the latter was replaced by a static stress equal to the peak of the cycle.

Another softened sample was fatigued for $1{\cdot}26 \times 10^6$ cycles at $\pm$ 20 tons/in$^2$ to develop a D.P.H. of 231, i.e. the same as that developed by $10^4$ cycles at $\pm$ 21 tons/in$^2$. The former sample was not permanently damaged by this treatment. When this sample was subsequently fatigued in pulsating tension at 0 to 21 tons/in$^2$, no failure was obtained up to $41 \times 10^6$ cycles. It could, therefore, be concluded that it was not so much the overall level of hardness to which the sample was brought which determined whether permanent damage was done, but the extent of localized deformation within each grain which was important. The more localized effect occurred at the higher stress, i.e. at $\pm$ 21 as compared with $\pm$ 20 tons/in$^2$. This was further borne out by the fact that when the sample, fatigued for $1{\cdot}26 \times 10^6$ cycles at $\pm$ 20 tons/in$^2$ to a D.P.H. of 231, was further fatigued at $\pm$ 20 tons/in$^2$, no failure occurred up to $25 \times 10^6$ cycles, i.e. a hardness of 231 D.P.H. developed by fatigue testing at $\pm$ 21 tons/in$^2$ was potentially more dangerous than when developed at $\pm$ 20 tons/in$^2$, the higher stress causing the more localized damage.

**Onset of Permanent Damage**

It was reported in a previous section that permanent damage was detected during reversed direct-stress fatigue testing of softened material after only 10,000 cycles at $\pm$ 21 tons/in$^2$, i.e. within 7% of the average expected life. Similar tests carried out at $\pm$ 26 tons/in$^2$ on material statically cold-worked by 20% indicated permanent damage within 25% of the average expected life, i.e. in both cases, damage occurred early for tests in reversed direct stress and at stresses just greater than their respective fatigue limits. In contrast, tests carried out in pulsating tension at a stress of 0 to 44 tons/in$^2$ (just greater than the fatigue limit), on material cold-worked by 20%, showed no damage at interrupted lives of the order of those obtained within the normal scatter of values at fatigue failure of the material. Tests at 0 to 48 tons/in$^2$, however, showed that damage occurred within 75% of the average expected life.

Thus permanent damage occurred at a very much greater fraction of the life in pulsating tension than in tension-compression. While permanent damage was detected in the latter within only 7 or 25% of the average life, the corresponding figure for pulsating tension was about 75 to 99%, i.e. cracks grow relatively slowly in tension-compression, but are almost catastrophic in pulsating tension. The rapid nature of the failure in the latter might be explained by the magnitude of the stresses required to obtain a fatigue failure being very much higher than in tension-compression and causing a crack, once formed, to propagate more rapidly. Another, though possibly less important, factor in determining when failure occurred, after permanent damage had been caused, was that every alternate cycle in tension-compression would have tended to close a crack, while every cycle in pulsating tension would have tended to open and propagate it if one were present.

Thus, considering the above results with those of the previous section, while a fully reversed direct stress was potentially more dangerous than a pulsating tensile one *of the same magnitude*, once a crack had been formed by either mode of stressing it was propagated more rapidly by the pulsating tensile stress, probably because of the latter's invariably much higher value.

## STRUCTURAL CHANGES DURING FATIGUE

X-ray diffraction photographs were taken by the back-reflection technique, using chromium unfiltered radiation, on the same transverse sections as were used for hardness measurement, but prior to these measurements. The results were similar to those obtained by others for mild steel,[14] $\alpha$-brass,[15] and copper,[13] in so far that the work-hardening caused by fatigue in reversed direct stress is accompanied by a blurring of the diffraction spots, but does not cause marked fragmentation or disorientation of the grains as obtains from statically applied cold work. The arcing of the diffraction spots and the complete rings observed recently by Kemsley[16] after high reversed stressing of copper were probably due to the fatigue stresses being well in excess of the proof stresses as pointed out elsewhere.[17]

Figure 7 shows the initial, as-softened structure, while Fig. 8 shows the structure after 100,000 cycles at $\pm$ 20 tons/in$^2$; a similar structure was observed after 25,000,000 cycles. Figure 8 shows blurring of the individual spots relative to the unfatigued condition. Figure 9 shows the structure after 134,000 cycles at $\pm$ 21 tons/in$^2$. For roughly the same life of 100,000 cycles, the degree of blurring increased with the applied stress and with the degree of fatigue hardening. However, the absence of grain fragmentation will be noted in these figures. For comparison, Fig. 10 shows the structure of an unfatigued sample statically cold-worked 10% to about the same hardness (248 D.P.H.) as that of Fig. 9. Grain fragmentation and disorientation are clearly visible in Fig. 10.

Since a stress of 21 tons/in$^2$ involves 0·07% plastic strain, it was of interest to know to what extent this contributed to the observed structure. The effect of applying this stress once only was to give only very slight blurring of the diffraction spots. There was a much greater difference in structure between a sample loaded only once to + 21 tons/in$^2$ and one fatigued for about 100,000 cycles at $\pm$ 21 tons/in$^2$, than for similar conditions at 22 tons/in$^2$.

The structure of a sample fatigued in pulsating tension for 16,000,000 cycles at 0 to 22 tons/in$^2$. was not very different from that of the sample loaded to + 22 tons/in$^2$ only once, though showing less blurring than a sample fatigued at $\pm$ 22 tons/in$^2$.

The cold-worked series of samples showed no significant change in structure as a result of fatigue testing, whether in reversed direct stress or in pulsating tension.

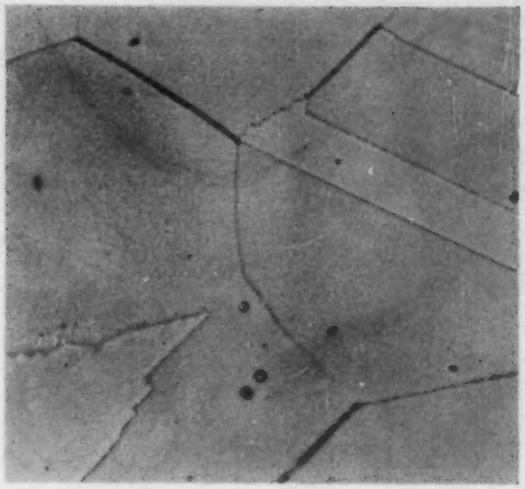


Fig. 11—Softened, ½ h/1050° C A.C. + 2·5 × $10^7$ cycles at ± 17 tons/in²; etched × 2000

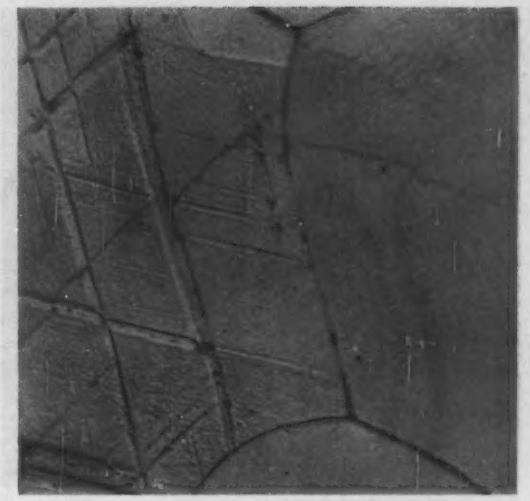


Fig. 12—Softened + 20% static cold work; electropolished and etched × 2000

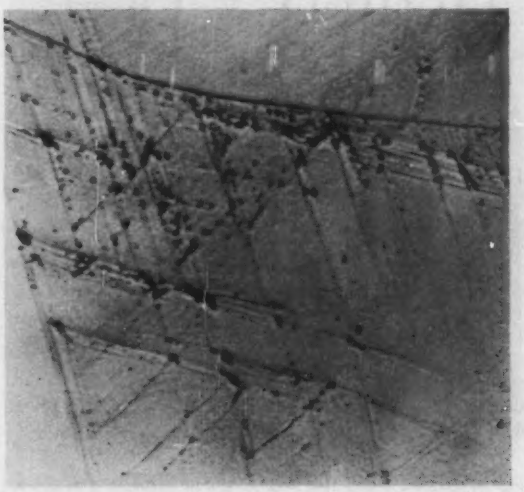


Fig. 13—Softened + 30% static cold work; etched × 2000

Fig. 14—Softened + $10^6$ cycles at ± 20 tons/in²; etched × 2000

**Figs. 11–14—Photomicrographs**

## MICROSTRUCTURES

The microstructures were observed both on the prior electropolished gauge lengths of the samples as fatigued without any further preparation, and also on the same transverse sections as were used for X-ray diffraction examination and hardness measurement. The latter sections were re-electropolished and etched for 1 min in 2% nital. Owing to the high manganese content of the steel, a certain amount of banding appeared in the microstructures which sometimes obtruded into the photomicrographs. This did not affect the fatigue characteristics.

The microstructure of N.M.C. in the softened condition consists of twinned austenite grains with a discontinuous precipitate of chromium carbide at the grain boundaries similar to that in Fig. 11. The alloy is most interesting in that slip can be made visible after sectioning and suitable polishing and etching as found in copper, α-brass, and other metals.[18] Thus Fig. 12 shows the effect of 20% static cold work in tension, after electropolishing and subsequent etching. Both fine and coarse slip lines are visible. Etching has caused pitting on some of them. This pitting effect was often more pronounced at the intersection of slip planes. It increased with cold work as shown by Fig. 13 which represents a sample cold-worked 30%, but was rare after only 10% cold work due to the relative absence of slip-plane intersections and coarse slip lines.

It was, therefore, expected that localized plastic deformation induced by fatigue testing and indicated by hardness increase might be revealed metallographically. For fatigue in reversed direct stress of softened samples, no metallographic changes were

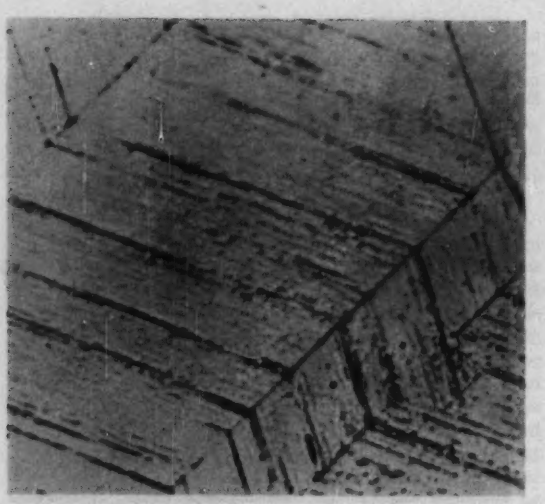


Fig. 15—Softened + $10^5$ cycles at $\pm$ 20 tons/in$^2$; etched × 2000

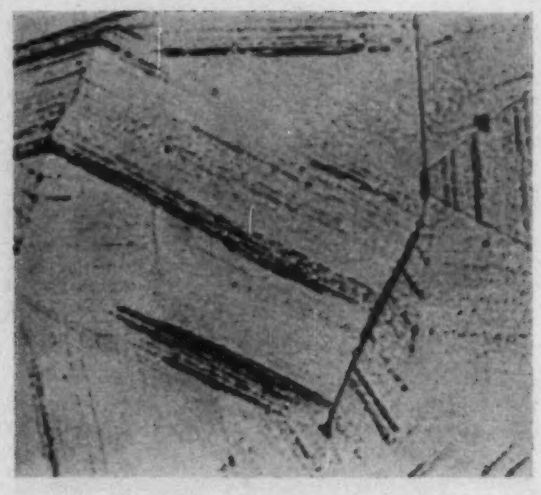


Fig. 16—Softened + $1{\cdot}34 \times 10^5$ cycles at $\pm$ 21 tons/in$^2$; etched × 2000

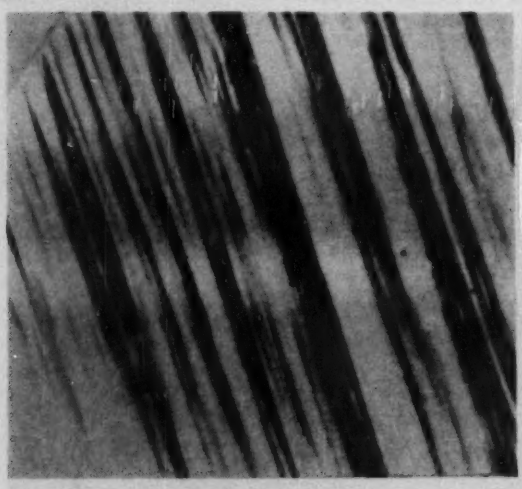


Fig. 17—Softened + $10^5$ cycles at $\pm$ 20 tons/in$^2$; external surface electro-polished and sample fatigued × 2500

Fig. 18—Softened + 20% cold work + $4 \times 10^4$ cycles at $\pm$ 29 tons/in$^2$; etched × 2000

**Figs. 15–18—Photomicrographs**

observed in transverse sections until appreciable hardening had occurred. Thus no changes were observed after $25 \times 10^6$ cycles at $\pm$ 17 tons/in$^2$, as in Fig. 11. After $10^4$ cycles at $\pm$ 18, 20, 21, or 22 tons/in$^2$, slip lines in many of the grains were delineated by rows of fine pits, as in Fig. 14, there being little difference in microstructure for the different stress levels corresponding to their roughly similar hardness values. For lives greater than $10^4$ cycles, slip-line delineation by pitting became more pronounced and localized with increasing number of cycles for the same stress as in Fig. 15 for $10^5$ cycles at $\pm$ 20 tons/in$^2$, and with increasing stress for the same number of cycles. Figure 16 shows the very localized disturbance on adjacent groups of planes after 134,000 cycles at $\pm$ 21 tons/in$^2$. This sample had failed in fatigue.

The structure revealed on the external surface of a test-piece fatigued for $10^5$ cycles at $\pm$ 20 tons/in$^2$ is shown in Fig. 17 and may be compared with Fig. 15. The microstructures on external surfaces showed similar relative effects as did those in internal sections. However, the former suggested disturbance over wider regions, i.e. greater adjacent numbers of planes, than did those in internal sections. The etching effect in internal sections may, therefore, be more indicative of the degree of localized disturbance, this possibly being greater at the centre of a broad cluster of slip planes such as appear on the surface.

There is also a similarity between the striations in Fig. 17 and those observed recently by Stubbington and Forsyth[19] on the fatigued surfaces of annealed Cu–Ni alloys which, of course, were also alloys of f.c.c. structure.

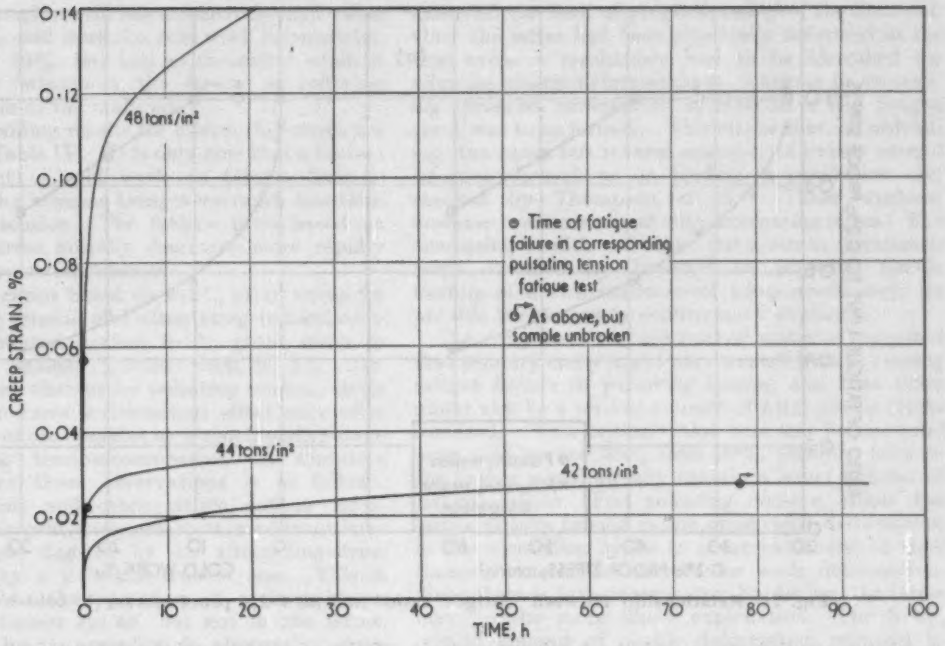



**Fig. 19—Creep curves for material cold worked 20%**

Turning now to the microstructures of prior statically cold-worked samples fatigued in reversed direct stress, the pitting effect which could now be taken as a sign of plastic deformation (static or dynamic) was found in varying degree in all the samples examined. The extent of deformation, as measured by the pitting effect and caused by fatigue, increased with applied stress for each series of statically cold-worked samples, but decreased with increasing amounts of prior static cold work. Figure 18 shows the microstructure of a sample cold-worked 20% and fatigued for 40,000 cycles at $\pm$ 29 tons/in². The difference in distribution of the pits between Figs. 18 and 12 clearly indicates that plastic deformation has occurred during fatigue testing at a stress of $\pm$ 29 tons/in², in material whose static 0·05% proof stress and limit of proportionality were 36·5 and 10·9 tons/in² respectively.

Finally, considering the microstructures of samples fatigued in pulsating tension, no change was detected in prior cold-worked samples, while softened samples showed only very faint traces of slip, and then only at stresses of the order of the 0·5% proof stress.

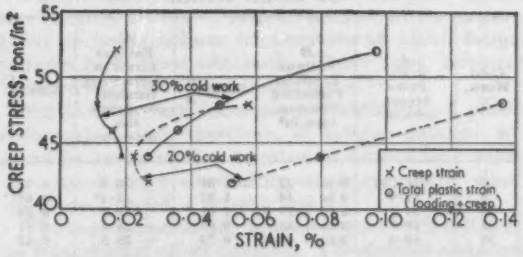



**Fig. 20—Plastic strain involved in creep tests**

## POSSIBILITY OF CREEP DURING PULSATING-TENSION FATIGUE TESTS

Because of the high pulsating tensile stresses which caused failure by fatigue in prior cold-worked test-pieces, it was thought that creep might play a role in the mechanism of failure. Creep tests were, therefore, carried out on material cold-worked 20% and 30% at the same maximum stress levels as were used in the pulsating tensile fatigue tests. These creep tests were run for at least the same time as the corresponding fatigue tests and often for considerably longer. All the creep tests carried out gave creep curves of a similar type showing only a primary and secondary stage, as illustrated in Fig. 19 for the 20% cold-worked material. Measurements were made of the total plastic deformation occurring on loading to the required creep stress and also of the total amount of creep strain occurring at maximum stress for a period of time equal to the fatigue life under pulsating tensile stress. The creep strain alone, and creep strain plus tensile plastic strain on loading, are plotted as a function of the applied stress in Fig. 20. Figure 19 shows that for material cold-worked 20%, fatigue failure at 0 to 44 and 0 to 48 tons/in² would have occurred at times corresponding only to the primary stage of creep. The fatigued sample remaining unbroken after 78 h at 0 to 42 tons/in² would have entered the secondary steady stage of creep. For material cold-worked 30%, fatigue failure at 0 to 52 and 0 to 48 tons/in² would also have occurred during only the primary stage of creep, failure at 0 to 46 tons/in² at the end of the primary stage, and failure at 0 to 44 tons/in² at well into the secondary stage. Figure 20 shows that there is no simple correlation between the

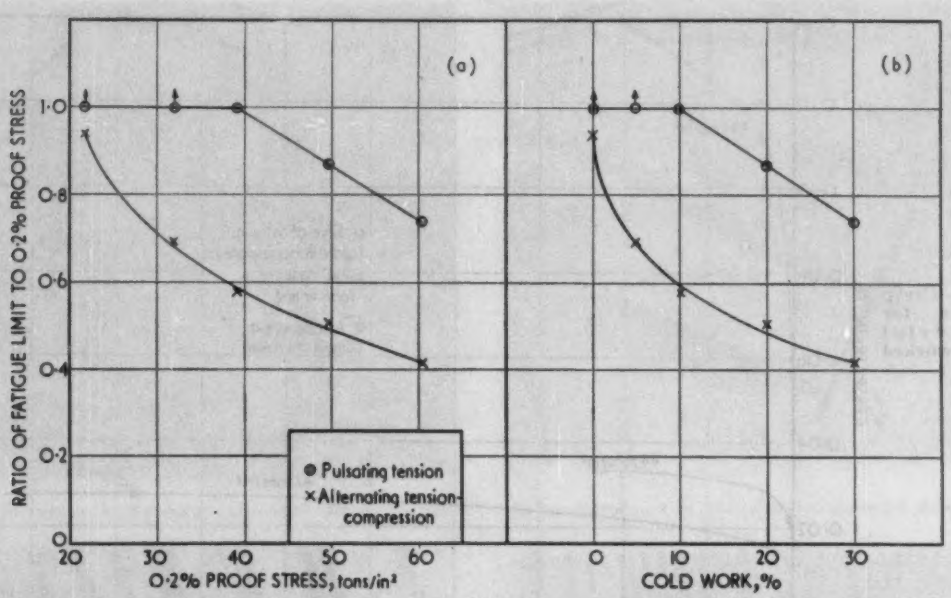



**Fig. 21—Relationship between 'fatigue ratio' and (*a*) 0·2% proof stress, (*b*) cold-work**

maximum applied stress and the total creep strain alone. However, there is almost a linear relationship between the maximum applied stress and the sum of the creep strain and plastic strain on loading. This might imply that for material cold-worked 20% and with a fatigue limit of 0 to 43 tons/in² there was a minimum total plastic strain required for fatigue failure in pulsating tension, this being about 0·066%; since material cold-worked 30% showed no definite fatigue limit even as low as 0 to 44 tons/in², the corresponding critical strain would be less than 0·026%. As the time the fatigue tests would be at the maximum stress would be less than the total fatigue life, because of the pulsating character of the stress, the creep strain attained would be less than that estimated from the creep curves. This, however, would not greatly affect the linear character of the relationship between applied stress and total plastic strain as described above.

In general, it seems that fatigue failures in pulsating tension occur at points corresponding mainly to the primary stage of creep. The more important factors seem to be (*a*) the total amount of plastic strain occurring on loading, and due to primary creep, and (*b*) the fact that significant plastic deformation occurs in cold-worked material.

## DISCUSSION

The present investigation set out to explain the limited beneficial effect of static cold work on the fatigue strength, as measured in reversed stressing, of an austenitic alloy steel relative to the corresponding increase in static tensile properties (especially proof stresses). On theoretical grounds, the comparison between the increase in static tensile properties (proof stresses) and the limited increase in alternating stress fatigue properties is unfair because the effect of the cold work is measured statically in tension and the fatigue tests are carried out dynamically in alternating tension and compression. A clearer understanding of the effect of static cold work on fatigue results is obtained if initially its effect on static tensile properties is compared with that on dynamic fatigue testing in tension only, and only thereafter with that on dynamic alternating stress since the latter introduces the complication of the Bauschinger effect.

For a fatigue test in which a constant stress is repeated in tension, the upper limiting value of the applied stress will be the yield point or, if there is no yield point, some fairly small, say 0·2%, proof-stress value of the material. Comparison can then be made between the 0·2% proof stress and the fatigue limit in pulsating tension for the several amounts of cold work. This has been done for the N.M.C. alloy steel and the results are shown in Table IV.

This shows that for pulsating tension, the gain in fatigue limit is the maximum possible up to 10% cold work. Thereafter the fatigue limit still increases with cold work but the fatigue ratio, $B/A$ in Table IV,

**Table IV**

**COMPARISON BETWEEN PROOF STRESS AND FATIGUE LIMIT FOR DIFFERENT AMOUNTS OF COLD WORK**

| Cold Work, % | *A* 0·2% Proof Stress, tons/in² | *B* Fatigue Limit in Pulsating Tension, tons/in² | Ratio $\frac{B}{A}$ | *C* Fatigue Limit in alternating tension-compression, tons/in² | Ratio $\frac{C}{A}$ |
|---|---|---|---|---|---|
| 0 | 21·75 | 0 to > 22 | > 1·01 | ± 20·5 | 0·94 |
| 5 | 31·9 | 0 to > 34 | > 1·07 | ± 22·2* | 0·695* |
| 10 | 39·1 | 0 to + 39·5 | 1·01 | ± 22·5 | 0·58 |
| 20 | 49·7 | 0 to + 43 | 0·87 | ± 25·5 | 0·51 |
| 30 | 60·4 | 0 to + 44·5 | 0·74 | ± 25·5 | 0·42 |

* Interpolated from Fig. 2

decreases, although it still has a relatively high value even after 30% cold work, i.e. cold work is beneficial; fully so up to 10%, but less so thereafter when it simultaneously introduces the means of reducing the fatigue ratio of the material.

The corresponding results for alternating stress are also shown in Table IV. It is only now that a limited beneficial effect of cold work on fatigue limit is encountered, the increase being very much less than for pulsating tension. The fatigue ratio based on 0·2% proof stress initially decreases more rapidly than that for pulsating tension.

The fatigue ratios based on 0·2% proof stress for both pulsating tension and alternating tension-compression are plotted against 0·2% proof stress in Fig. 21*a*, and against % cold work in Fig. 21*b*. These show that whereas for pulsating tension, static cold work introduces a deleterious effect only after 10%, such an effect operates at a much earlier stage for alternating tension-compression. A tentative explanation for these observations is as follows. The dislocations and other lattice defects introduced by static cold work are more readily utilized to cause fatigue damage by an alternating-stress system than by a pulsating-tension one. This is probably due to the operation of a Bauschinger effect in the former system but not in the latter. The evidence for its operation in alternating stress seems to have been provided by the marked hardening so obtained in contrast to the slight hardening in pulsating tension. How the lattice defects are utilized to cause fatigue damage can only be surmised. For alternating stresses it may be that by the repeated to and fro movement of dislocations and their intersection with one another, vacant lattice sites (V.L.S.) are generated.[20] Local concentrations of these on the slip planes may, by a staggered chain effect, be sufficient to form a small viable crack under the action of the applied stress. The fact that an etching (pitting) effect was obtained along the presumed slip planes in internal sections of samples fatigued in reversed direct stress, similar to that observed at the intersections of slip planes in statically deformed samples where V.L.S. would be expected, might be evidence for the existence of V.L.S. in fatigued samples. Microhardness measurements did not show these lines of pits in fatigued samples to be very much harder than adjacent regions, in line with observations on copper.[21] Lacombe and Yannaquis[22] observed preferential etching at the grain boundaries of greatest misfit of high-purity aluminium, i.e. in regions in which there would be a high proportion of V.L.S. or kindred defects. Mott[23] has argued against the vacancy theory of fatigue because of its inoperability at liquid helium temperature at which fatigue failures have been obtained. There may, however, be more than one fatigue mechanism.[24]

Static cold work increases the difficulty of plastic deformation and, therefore, of fatigue damage, but provides an increasing number of dislocations whose movement under alternating stress eventually allows the formation of a fatigue crack.

The case for pulsating tension is more difficult since no Bauschinger effect operates. The stresses employed to obtain fatigue failures in pulsating tension all exceeded the limit of proportionality of the material. Once the latter had been plastically deformed in the first cycle, a mechanism had to be identified for allowing plastic deformation to continue in succeeding cycles as, presumably, it must have if a fatigue crack was to be formed. This means that, on unloading, the same but reverse sequence of events cannot be gone through as on loading, a conclusion also reached by Thompson *et al.*[25] These workers, however, were concerned with alternating stress. The decreasing width of the stress/strain hysteresis loops obtained by Brown[26] on repeated tensile loading of drawn carbon-steel wires would seem to provide the necessary confirmatory evidence.

The creep tests on cold-worked material suggested that primary creep might play a small part in causing fatigue failure in pulsating tension and that there might also be a critical amount of total plastic strain involved. This critical value was less for material prior cold-worked 30% than 20%, possibly because the former would already contain a larger number of lattice defects. For pulsating tension either the lattice defects formed in one cycle cause deformation in the succeeding cycles to occur elsewhere, or they themselves are the sources for such deformation. Since there is little macroscopic hardening, the latter may be the more likely explanation. The 8·6% critical amount of plastic deformation required to obtain a fatigue failure in pulsating tension could be interpreted as that necessary to provide the minimum number of dislocations whose local movement would assure the formation of a sufficient number of V.L.S. to form a viable crack. Precisely how these V.L.S. would be formed is not clear and requires further study.

The critical hardness level of 231 D.P.H. (equivalent to about 7% static cold work) required to obtain a fatigue crack by alternating stress of $\pm$ 21 tons/in$^2$ in softened material has a similar significance to the above figure of 8·6% critical amount of cold work. However, such a hardness level (231 D.P.H.) developed at a lower fatigue stress ($\pm$ 20 tons/in$^2$) or by static cold work would not subsequently have caused fatigue failure at $\pm$ 20 or $\pm$ 21 tons/in$^2$ respectively. This strongly indicates the localized nature of the damage associated with a particular reversed fatigue stress. Davies *et al.*[27] have also reported a critical degree of macroscopic hardening, although their work has been criticized[17] on the grounds that the stresses used were of such a level as to have caused significant plastic deformation and, therefore, strain hardening simply on loading. Nor can failure in alternating stress have been due to an exhaustion process since the maximum hardness reached just above the fatigue limit was 247 D.P.H. while the hardness at the tip of a tensile fracture was 557 D.P.H.

Finally, some comment should be made on the fact that light tempering after cold working failed significantly to improve the fatigue strength. Nowick[28] obtained high internal friction and low dynamic Young's modulus values immediately after cold-working polycrystalline iron. He explained the subsequent recovery of these values on treatment at temperatures less than those required for recrystallization by the migration of unstable dislocations

to more stable sites. If such dislocation movements also occur in the present austenitic alloy steel, it would imply that fatigue failure was due initially to more thermally stable dislocation arrays. As vacant lattice sites are also believed to migrate at these moderate temperatures, the results would also imply that such tempering does not cause their aggregation into potentially harmful voids or cracks. It is also possible that the number of vacant lattice sites generated during the fatigue process is considerably greater than the number involved in migration during tempering, thus reducing the significance of the latter vacancies with respect to their effect on the fatigue process. Some idea of the nature of the more thermally stable dislocation arrays in this and other cold-worked alloys might be useful in helping to elucidate their fatigue mechanism.

## SUMMARY AND CONCLUSIONS

(1) It is suggested that from the theoretical viewpoint unfair criteria have hitherto been used for assessing the effect of cold work on fatigue strength. A clearer understanding is obtained (*a*) if the effect of cold work on static tensile properties (especially proof stresses) is compared initially with its effect on the fatigue limit determined dynamically in tension, and only thereafter with that on the fatigue limit determined dynamically in alternating stress; and (*b*) if the fatigue ratio is considered as the quotient of the fatigue limit and the yield point or a small proof-stress value.

(2) Cold work has been found to be simultaneously beneficial and deleterious, the balance depending on the extent of cold work and the mode of stressing in fatigue. It is beneficial in that it restricts plastic deformation and so hinders fatigue damage. It is deleterious in that it introduces dislocations whose movement can lead to fatigue-damaged zones.

(3) For an austenitic alloy steel, the effect of static cold work in tension was, for fatigue in pulsating tension, to give a fatigue ratio based on 0·2% proof stress of 1·0 for up to 10% cold work. Thereafter the fatigue ratio decreased although it was still 0·74 after 30% cold work. For fatigue in alternating tension and compression a limited beneficial effect of cold work was found, the fatigue ratio dropping from 0·94 in the softened condition to 0·42 after 30% cold work.

(4) The markedly inferior fatigue limits and ratios for alternating stress as compared with pulsating tensile stress were attributed to the operation of a Bauschinger effect in the former and not in the latter. This effect allows the dislocations introduced by the cold work to be utilized more readily to form a fatigue-damaged zone. The absence of a Bauschinger effect in pulsating tension allows the material to withstand higher stresses before sufficient plastic deformation can occur to form a fatigue-damaged zone. Supporting evidence for this is provided from hardness measurements and from metallographic and X-ray diffraction examination.

(5) Light tempering treatments after cold work, which removed the peak residual microstresses, failed to raise the fatigue limit in alternating stress.

(6) Fatigue cracks were detected within 10% and only after 75% of the average lives in alternating stress and pulsating tension, respectively.

(7) Fatigue cracks formed in alternating stress were found to propagate 100 to 200 times more readily by further cycles of alternating stress than by cycles of pulsating tensile stress of the same magnitude, i.e. crack propagation in alternating stress occurred by a mechanism probably akin to that of its formation and was not solely dependent on the joint effects of stress concentration at the tip of the crack and the applied alternate tensile cycle.

(8) A critical amount of static cold work was required before fatigue failure could be obtained in pulsating tension, and likewise of dynamic cold work for failure in alternating stress of initially softened material.

(9) Creep may have been a factor in the pulsating tensile fatigue tests.

## Acknowledgments

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## References

1. H. R. SANDER and M. HEMPEL: *Arch. Eisenhütt.*, 1952, vol. 23, pp. 299–320.
2. R. CAZAUD: " The Fatigue of Metals ", pp. 102–105: 1953, London, Chapman & Hall.
3. R. W. NICHOLS: *J.I.S.I.*, 1956, vol. 182, pp. 337–347.
4. J. R. TOWNSEND and C. H. GREENALL: *Amer. Soc. Test. Mat.*, 1929, vol. 29, pp. 353–364.
5. C. H. GREENALL and G. R. GOHN: *Ibid.*, 1937, vol. 37, pp. 160–191.
6. J. G. KAUFMAN and E. D'APPOLONIA: *Ibid.*, 1955, vol. 55, pp. 999–1012.
7. B. CINA: To be published.
8. B. CINA: *Metallurgia*, 1957, vol. 55, No. 327, pp. 11–19.
9. B. CINA: To be published.
10. N. H. POLAKOWSKI: *Amer. Soc. Test. Mat.*, 1952, vol. 52, pp. 1086–1097.
11. N. H. POLAKOWSKI and A. PALCHOUDHURRI: *Ibid.*, 1954, vol. 54, pp. 701–712.
12. L. F. COFFIN jun. and J. H. READ: " Proceedings of the International Conference on Fatigue of Metals, 1956," pp. 415–423: London, Inst. Mech. Eng.
13. F. P. BULLEN, A. K. HEAD, and W. A. WOOD: *Proc. Roy. Soc.*, 1953, A, vol. 216, pp. 332–343.
14. H. J. GOUGH and W. A. WOOD: *Ibid.*, 1936, A, vol. 154, pp. 510–539.
15. W. A. WOOD and P. L. THORPE: *Ibid.*, 1940, A, vol. 174, pp. 310–321.
16. D. S. KEMSLEY: *J. Inst. Metals*, 1957, vol. 85, Pt. 9, May, pp. 417–421.
17. B. CINA: *Ibid.*, 1956–57, vol. 85, Prelims, Proceedings, Discussions, and Name Index, pp. 565–566.
18. L. E. SAMUELS: *Ibid.*, 1955, vol. 83, Pt. 7, March, pp. 359–368.
19. C. A. STUBBINGTON and P. J. E. FORSYTH: *Ibid.*, 1957, vol. 86, (2), Oct., pp. 90–94.
20. F. SEITZ: *Advan. Phys.*, 1952, vol. 1, No. 1, pp. 43–90.
21. D. S. KEMSLEY: *J. Inst. Metals*, 1956, vol. 85, Pt. 4, Dec., pp. 153–157.
22. P. LACOMBE and N. YANNAQUIS: *Métaux et Corrosion*, 1947, March, vol. 22, No. 259; pp. 35–37.
23. N. F. MOTT: *Proc. Roy. Soc.*, 1957, A, vol. 242, pp. 145–147.

24. B. CINA: "Proceedings of the International Conference on Fatigue of Metals, 1956," pp. 885–886: London, Inst. Mech. Eng.
25. N. THOMPSON, C. K. COOGAN, and J. G. RIDER: *J. Inst. Metals*, 1955, vol. 84, part 3, Nov., pp. 73–80.
26. R. S. BROWN: *J.I.S.I.*, 1949, vol. 162, pp. 189–200.
27. R. B. DAVIES, J. Y. MANN, and D. S. KEMSLEY: "Proceedings of the International Conference on Fatigue of Metals, 1956," pp. 551–555: London, Inst. Mech. Eng.
28. A. S. NOWICK: *J. Appl. Phys.*, 1954, vol. 25, No. 9, pp. 1129–1134.

*Letter to the Editor*

## Rapid Reverse Tranformation of Ferrite to Austenite on Tempering a Cold-Rolled Stainless Steel

COLD ROLLING, drawing, or other forms of cold deformation when applied to certain grades of austenitic steel can produce a martensitic type of transformation of austenite to ferrite. This effect is well known and an extensive general investigation was carried out by Cina.[1] In connection with the study of a steel in this class, the writers have observed what appears to be a rapid reverse transformation of ferrite to austenite, the ferrite having first been produced by cold deformation. The steel investigated had the following composition: 0·08%C, 17%Cr, 2½%Ni, 8%Mn, 0·15%N. The properties of this type of austenitic steel have been described by Carney[2] and by Franks, Binder, and Thompson.[3] The authors have not, however, seen any mention of the effect described below.

Cold-rolled strip after 80–90% reduction showed an almost complete transformation of austenite to ferrite (or martensite). On reheating for 2 h at 200° C, approximately half of the ferrite reverted to austenite. Reheating a series of samples for the same time of 2 h at temperatures up to 500° C showed practically no difference in these amounts of austenite and ferrite. Above 500° C the amount of ferrite diminished more or less progressively until the fully austenitic structure was again reached in a specimen reheated to 750° C. The facts are represented by the crosses and solid line in Fig. 1. These results were obtained by X-ray diffraction patterns. (Reheating specimens after annealing at 1050° C and without cold-rolling produced no ferrite after heating for 2 h at temperatures from 200° to 400° C).

Further experiments involving longer periods of heating (16 and 100 h) of samples of cold-rolled strip showed very little, if any, increase in the relative amount of reformed austenite, and the broken line in Fig. 1 represents possible proportions of the two phases for equilibrium. For reasons stated below this may not be true equilibrium.

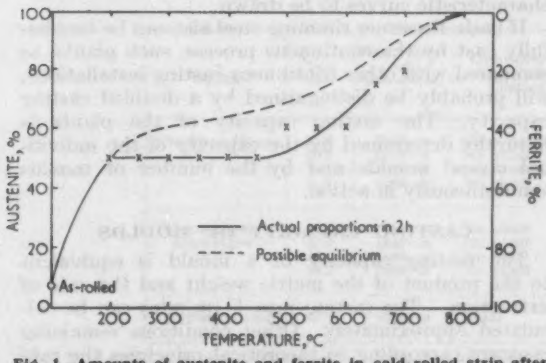


**Fig. 1—Amounts of austenite and ferrite in cold-rolled strip after reheating**

This rapid reverse transformation of ferrite to austenite should be quite general in stainless steels that undergo the forward transformation of austenite to ferrite on cold-rolling, but not in fully stable austenitic steels. The authors have not, however, had the opportunity to examine other steels. In the present case particular interest attaches to the fact that, whereas on reheating at 200° C for 2 h there is a rapid change of about half the ferrite to austenite, reheating at 450° C for the same time (or longer) does not produce a markedly greater amount of austenite. This suggests that, although the cold-rolling has produced an almost fully ferritic structure, a proportion at least of this ferrite was metastable at 200° C and probably at lower temperatures too. The metastable ferrite transforms rapidly back to austenite. This could take place by a simple reversal of the mechanism by which plastic deformation had originally transformed the original austenite to ferrite. The precise mechanism would be very difficult to establish, and we are tempted to make what can only be speculations at this stage.

Two of the possible factors that could influence this reversal may be mentioned. The annealing treatments could have released internal microstresses, i.e. reverse transformation could be assisted by a form of stress relief or recovery on a micro scale. Alternatively, the steel contains an appreciable amount of nitrogen as well as some carbon, and both these elements are strong austenite formers and have very low solubility in ferrite. Furthermore, these are the only two elements which can diffuse rapidly at temperatures between 200° C and 400° C. The ferrite must be heavily supersaturated with regard to these elements, and the formation of a considerable proportion of austenite into which N and C atoms could diffuse would therefore accommodate these atoms much more readily. Indeed, it may be that stresses due to supersaturation themselves contribute to the forces causing the reverse transformation, but are assisted by the diffusion of C and N which is necessary in order to approach the equilibrium partition between austenite and ferrite.

The possibility of further diffusion of other elements, such as Mn and Ni, could be considered. This would be so slow at lower temperatures that the state represented very approximately by the broken line in Fig. 1, referred to as 'equilibrium,' would mainly represent proportions of austenite and ferrite determined by carbon and nitrogen. The partition of Mn and Ni between the two phases is much smaller and true equilibrium will not be markedly different from the 'provisional equilibrium.'

L. PRYCE (*Samuel Fox and Co., Ltd.*)
H. HUGHES, K. W. ANDREWS (*United Steel Companies, Ltd., Swinden Laboratories*)

1. B. CINA: *J.I.S.I.*, 1954, vol. 177, pp. 406–422.
2. D. J. CARNEY: *Blast Furn. Steel Plant*, 1955, Dec., pp. 1337–1380.
3. R. FRANKS, W. O. BINDER, and J. THOMPSON: *Trans. A.S.M.*, 1955, vol. 47, pp. 231–268.

# Continuous Casting of Steel in Western Germany

*By K. G. Speith and A. Bungeroth*

SYNOPSIS

After a brief historical review, the paper examines several fundamental aspects of continuous casting. First, the casting rate of killed and rimming steels and steels of different types—open-hearth, electric, and basic Bessemer—is discussed, and also the problems relating to the rate of extraction and solidification of ingots. This is followed by a comparison between siphon ladles and nozzle ladles, and a discussion on the use of an intermediate receiver to make the supply uniform or to distribute the steel to the several lines of the plant. Next, problems relating to the ingot mould and, in particular, to its method of suspension are dealt with. The paper ends with a study of methods of increasing the casting rate and of various special constructional characteristics. 1620

## DEVELOPMENTS IN WESTERN GERMANY UP TO THE PRESENT TIME

DURING World War II an attempt was made in Germany to develop the continuous casting of steel on a wider basis. At the end of the war, however, these trials lapsed. They were begun again in early 1949 by Junghans, using a development plant at Schorndorf. Further single and two-strand experimental plants were started in 1950 by Mannesmann at Duisburg-Huckingen and in 1952 by the Rheinischen Röhrenwerken at Mülheim.[1] These two plants are no longer in operation.

As a result of this development work, a four-strand continuous casting machine for handling 35-ton melts has been in operation since mid-1954 in the electric steelplant of Mannesmann-Hüttenwerke A.G. at Huckingen (Fig. 1). It is regarded as a semi-commercial plant since it can deal with only part of the electric steel production and cannot exceed an output of about 800 tons per month. Low-alloy special steels are cast in 8–10-in. (200–240 mm) square ingots for rolling into tube rounds, and round ingots of 10–12 in. (260, 275, and 300 mm) dia. for direct use in the tube mills. With suitable programme conditions and with another 35-ton furnace, the monthly capacity of the plant would be about 7000 tons. The multistrand plant allows further development work to proceed without disturbing production casting. In 1950, Mannesmann joined Siegfried Junghans (Schorndorf), Vereinigte Leichtmetallwerke (Bonn), and Wieland-Werke (Ulm, Donau) to form the Stahlstranggussgemeinschaft (Continuous Steel Casting Association—S.S.G.). In 1952, the S.S.G. and the Österreichischen Strangguss Interessengemeinschaft (the Austrian Continuous Casting Community—ÖSIG) made arrangements for close technical collaboration between the two groups. Further agreements with Demag, Duisburg, authorized the building of continuous casting plants of the S.S.G. and ÖSIG types.

## CONDITIONS FOR CONTINUOUS CASTING

The decision to operate a continuous casting plant should be made only if it is certain that:

(1) The quality of the product is in no way inferior to that obtained by rolling down from the ingot
(2) There is a reduction in costs compared with production
(3) The operation presents no complications and the plant is large enough to avoid delays in tapping the melting furnace that supplies it.

## ADJUSTMENT OF CASTING PLANT TO MELTING UNITS

A report has been published[2] on adjusting the capacity of a continuous casting plant to a casting time suitable to the size of the ladle. Plants must be designed so that, using ordinary ladles, in casting 35 tons or more, casting does not take more than 1 h, and with ladles of 5–35 tons capacity, casting takes 30–60 min. This ratio is valid for open-hearth and electric steels, but its application to basic Bessemer steels is limited.

Figure 2 gives data determined by two companies[3] on casting basic Bessemer rimming steels, and also values obtained in a teeming test carried out by the Westfalenhütte, Dortmund. It covers charges of different weights, with varying casting times, with and without ladle skulls, and normal and hot melts with converter final temperatures of $\leqslant 1645°$ or $> 1645°$ C. The longer casting times for the open-hearth and electric steels might also apply to the basic Bessemer rimming steels if they were brought to the same temperature. However, in basic Bessemer practice high casting temperatures cannot be maintained in continuous operation. The formation of ladle skulls as a result of over-long casting cannot be tolerated, and so longer casting times are permissible only in normally hot melts. These are shown in the graph by open circles and are to the left of Fig. 2*a* about halfway below curve 1 (open-hearth and electric steel). All the values lying above are attained only in superheated charges (crosses) or with skull formation (full circles). These experimental values, although inadequate for a definite statement, permit provisional characteristic curves to be drawn.

If basic Bessemer rimming steel also can be successfully cast by the continuous process, such plants, as compared with other continuous-casting installations, will probably be distinguished by a doubled casting capacity. The casting capacity of the plants is naturally determined by the capacity of the individual strand moulds and by the number of moulds simultaneously in action.

## CASTING CAPACITY OF MOULDS

The casting capacity of a mould is equivalent to the product of the metric weight and the rate of extraction. The casting rate $V$ (m/min) can be calculated approximately. Other conditions remaining constant, according to theoretical principles the rate of casting for a certain shape of cast section varies with

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This is a slightly abridged version of the paper presented at the 10th Technical Session in Charleroi of the Journées Internationales de Sidérurgie.

The authors are with Mannesmann-Hüttenwerke AG, Duisburg, Germany.

the diameter or edge length $D$ mm corresponding to the equation

$$V = \frac{f}{D} \quad \ldots\ldots(1)$$

in which $f$ is an empirical factor. For circular dimensions $f$ is usually above 90, and recently, under suitable conditions, attained a value of 300. In square and rectangular castings $f$ lies between 115 and 350.

These varying extraction rates are only the maximum possible rates attainable in technical processes. High values are achieved only by the use of special measures. Experience has shown that, for reasons of quality, lower casting rates must be chosen.

For sheet bar and flat rectangular shapes a simple approximate calculation of the possible rate of extraction can be made with the equation

$$V = \frac{f}{(2LD)/(L + D)} \quad \ldots\ldots(2)$$

where $L$ is the width and $D$ the thickness of a continuously cast sheet bar (mm). According to experience, $f$ is between 150 and 200.

As Table I, column 8, shows, strands with the same metric weight but different section attain very different hourly outputs. Furthermore, comparing columns 8 and 9 shows that different outputs are possible with a single shape, by different methods of working.

## SOLIDIFICATION RATE

The solidification rate in continuous casting or the depth of the pasty condition (partial solidification) is a determining factor in designing a casting plant. Unlike non-ferrous metals, in the case of steel, the section is several metres long owing to the low thermal conductivity of iron and the correspondingly higher casting rate. The height of the plant is thus determined by the anticipated maximum length of this partially solidified stage. Only below this can the ingot be gripped by pinch rolls etc. without rupture.

The maximum length of partial solidification $S_{max}$ (mm), or the distance determined by it between the top edge of the mould and the pinch rolls, must be calculated from the casting dimensions of the production programme. This is usually derived for the heaviest billet section from the maximum production of the rate of casting $V_{max}$ (m/min) and the accompanying freezing time of the billet $T$ (min):

$$S_{max} = V_{max} \times T \quad \ldots\ldots(3)$$

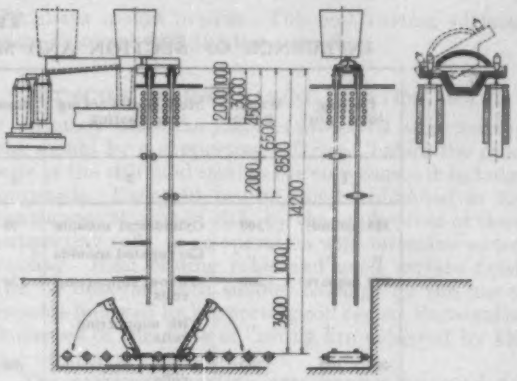



Fig. 1—Four-strand continuous-casting plant, Mannesmann-Hüttenwerke AG

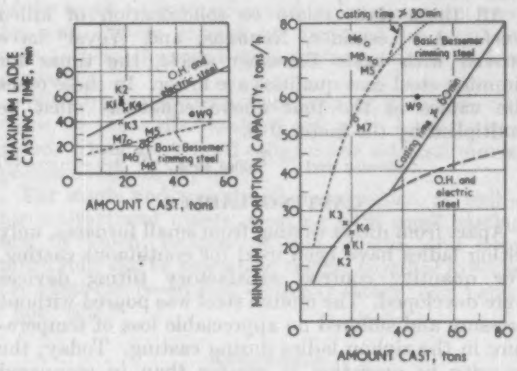
With steel, cooling with sprayed water affects the length of the solidifying section.

Cooling is carried out more effectively by adapting it to the conditions in a stationary ingot: freezing of the rim is accelerated only until security has been attained against breakout, while the core is allowed to cool in air. The freezing time of round and square castings is:

$$T = D^2 \times 0{\cdot}00033 \text{ min} \quad \ldots\ldots(4)$$

Klein[5] gives, in a simplified form, for round billets of 3–18 in. (80–450 mm) dia. the following freezing times:

$$T = \left(\frac{D\phi + 52}{74{\cdot}5}\right)^2 \quad \ldots\ldots(5)$$




| Works | Test No. | End Temp. of Converter, °C | Condition of Ladle after Casting | Symbol | Steel Cast, tons | Total Casting Time, min | Casting Capacity of Ladle, tons/h |
|---|---|---|---|---|---|---|---|
| Klockner-Haspe | K.1 | 1645—n | Cascade skull | ● | 18·4 | 55·5 | 19·9 |
| | K.2 | 1670—h | No skull | × | 18·0 | 57·6 | 18·7 |
| | K.3 | 1675—h | No skull | × | 17·7 | 40·0 | 26·6 |
| | K.4 | 1685—h | No skull | × | 20·2 | 50·0 | 24·2 |
| Mannesmann-Huckingen | M.5 | 1635—n | No skull | ○ | 29·5 | 25·5 | 69·5 |
| | M.6 | 1640—n | No skull | ○ | 26·5 | 21·5 | 74·0 |
| | M.7 | 1645—n | No skull | ○ | 21·5 | 24·0 | 53·7 |
| | M.8 | 1680—h | No skull | × | 27·5 | 23·5 | 70·2 |
| Westfalenhütte | W.9 | 1620—n | Skull | ● | 46·0 | 46·0 | 60·0 |

Fig. 2—Ladle casting experiments with basic Bessemer rimming steel: quantity/casting-time and quantity/casting-output diagrams (n = normal, h = hot)

**Table I**

**INFLUENCE OF SECTION AND METHOD OF WORKING ON OUTPUT**

| Casting Size, mm | Weight, kg/m | Method of Working or Casting | Rate Factor, *f* | | Rate of Casting, m/min | | Output, tons/h | | Efficiency Ratio as Compared with Normal | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 225 (round) | 300 | Cylindrical moulds | 95 | | 0·425 | | 7·5 | | 1·0 | |
| ,, ,, | ,, | Corrugated moulds | | 190 | | 0·850 | | 15·0 | | 2·0 |
| 200 (square) | 300 | Without supporting rolls | 130 | | 0·650 | | 12·0 | | 1·6 | |
| ,, ,, | ,, | With supporting rolls | | 200 | | 1·000 | | 18·0 | | 2·4 |
| 400 × 100 | 300 | (Without supporting rolls) | (80) | | (0·500) | | (9·0) | | (1·2) | |
| ,, | ,, | With supporting rolls | | 190 | | 1·200 | | 22·0 | | 2·9 |

where $\phi$ = dia. (mm) and for square billets of (70–400 mm) edge lengths the times:

$$T = \left(\frac{DE + 46}{66}\right)^2 \quad \ldots\ldots(6)$$

where $E$ = edge length (mm).

With sheet bar of thickness $D$ mm, the freezing times range between the limiting values:

$$D^2 \times 0{\cdot}00033 < T < D^2 \times 0{\cdot}00111 \quad \ldots\ldots(7)$$

When, in continuous casting of slabs or sheet bars, cooling is intensified by spray water, the times for freezing are quite close to the first-mentioned minimum values.

All these data relate to solidification of killed steels. As Kosmider, Neuhaus, and Weyel[3] have proved with basic Bessemer steels, the times for rimming steel cast qualities are lower. In these cases the values of the four above equations must be multiplied by the factor 0·6.

$$T_{\text{rimming steel}} = T_{\text{killed steel}} \times 0{\cdot}6 \quad \ldots\ldots(8)$$

## CASTING LADLES

Apart from direct casting from small furnaces, only tilting ladles have been used for continuous casting. For quantity control, satisfactory tilting devices were developed. The molten steel was poured without pressure and suffered no appreciable loss of temperature in the siphon ladles during casting. Today, the security in operation is greater than in stoppered ladles. However, tilting furnaces are expensive to operate. Moreover, with larger ladle weights difficulties in design arise. Above all, with these ladles, a parallel running charge is practically impossible both in continuous casting and in the ordinary ingot casting pit.

These were the reasons why at Huckingen a change was made from tilting vessels to stoppered ladles, although up to then the use of stoppered ladles in continuous casting had been declared impossible. However, development since that time has justified the method, first used in 1952.

## INTERMEDIATE RECEIVER

In single-strand casting using tilting ladles quantity control is generally regulated by operating the ladle-tipping device, after which the intermediate receiver took over the direction of the casting stream.

Fluctuations in the amount of steel flowing out of the ladle per unit of time could, using continuous flow from an intermediate receiver without controlling stoppers, be checked only in certain circumstances. It was not always possible to avoid fluctuations of the theoretical casting capacity by faster or slower extraction of the ingot.

With 2-, 3-, and even 4-strand continuous-casting plants, quantity control by the ladle alone can be used. The intermediate receiver must also distribute the steel to the individual moulds. With two-strand operation the ladle stream regulating the output is divided by a tilting runner into two casting streams, adjusted to the casting capacity of the moulds. If further distributing elements are added, symmetrically arranged, distribution to three or at most four moulds is possible. Since the ladle is perfectly controlled, the method is very adaptable to service. However, a greater temperature loss and greater danger of oxidation must be taken into account, since one or two additional intermediate cascades occur. However, fluctuations in the casting capacity of the ladle have a detrimental effect on all the moulds.

From the point of view of quality, the ingot should be cast at a constant rate. Any delay in extraction leads to a local advance of freezing within the solidifying section. This in turn produces constriction of the still fluid core and leads to the formation of secondary pipe below the constricted areas.

This detrimental result may be prevented from affecting all the moulds if the stream is controlled not only in the ladle but also in the distributor to each mould. Individual control for each mould, which is not practical with more than four strands, can be carried out with smaller stopper ladles, making it possible to regulate the level of the casting for each mould. The ladle merely fills the distributor at the start of teeming and then maintains the level. In such distributors it is advisable to equalize the fluctuations of the flow from the ladle by maintaining suitable reserves in the receiver.

Control stoppers for individual moulds permit instantaneous correction of the output of the casting

stream with adequate regulating accuracy between zero to the top limiting output, determined by the diameter of the nozzle $d$ and the height when filled $h$ (mm). The maximum output $L$ of a nozzle (tons/h) is provided approximately from equation (9), due to Jaicks, Kraay, and Tenenbaum[6]:

$$L = \frac{d^2\sqrt{h}}{375} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

For reasons of heat technology

(1) The ratio of the filling volume to the total surface area (i.e. the sum of all the limiting surface of the fluid steel in the distributor) should be as great as possible.
(2) The time taken for the steel to pass through should be kept as low as possible, which otherwise expressed means high rate of flow. However, it is advisable not to exceed certain limiting speeds.

In the interests of maintenance, renewal, and preheating, it is preferable to keep the distributor small. In multi-strand plants the moulds must be placed close together.

## MOULD DESIGN

Of the essential units which bring about the solidification of steel between the casting level and the end of the semi-solid condition, the first item is the mould. Within its range rim solidification must be so far advanced (about 15 mm) that the partially solidified ingot can, with adequate working safety, be taken out below the mould. Mould designs vary considerably; water-cooled designs are usually made only from copper or copper alloys, with both thick and thin walls. Separate types may be distinguished, such as those for moulding tubes or billets and multi-sectional moulds consisting of plates.

No single mould design is yet in widespread use. The technical suitability, together with the purchase price, the maintenance required, and the life, are the decisive factors. Fortunately, cost per ton of output is only a fraction of that for moulds in stationary casting.

## MOULD MOTION

Owing to the poor thermal conductivity of ferrous materials, below the level of casting is formed at first only a thin-walled chilled tube, which slides along the sides of the mould wall. Frictional forces must be overcome, so that, with adequate thickness and strength of the chill, they will not cause transverse cracks or ruptures. With increasing extraction rate, however, the chill becomes thinner and its resistance to tensile stresses is diminished. By periodic release of the tensile stress, the chill can be kept from fracture. Correct adjustment of the mould stroke and of the frequency are of decisive importance.

At Huckingen the Junghans mould motion has been used from the first; compared with immobile casting moulds it has definite advantages, evident only at high rates of casting. Also it shows that intermittent relative motion is not always essential.

In this connection some experimental tests[7] are of interest. They were carried out at the Red October works in Russia, first with a stationary mould, then with a mould mounted on springs, and finally with the Junghans mould motion. The best casting surfaces were obtained with the last-named.

## METHODS OF INCREASING CASTING RATE

In many cases the ingot is protected after leaving the mould by a supporting roll cage, before the pressure of the still fluid steel in the core causes it to bulge outwards. Excellent results can be obtained in the continuous casting of slab, by the application of these supporting rolls, in co-operation with intensive water-cooling. High casting rates and good surface finish can be obtained with smaller castings by the use of moulds followed by supporting roll cages. Substantial increases of the rates of casting are achieved by the use of ' corrugated ' moulds.[8]

The maximum casting rate cannot be used for most steels for reasons of quality. The extraction rate and direct cooling can be increased only to the point where they affect the internal quality of the ingot. The limits of extraction rate vary according to the quality of the steel.

## SPECIAL DESIGN CHARACTERISTICS

In spite of the greater area required for the plant, the authors favour multi-strand installations as more practical.

Different types of withdrawal devices are available according to the weight of the ingot derived from the weight of the casting and from the maximum practical extraction length.

For the light section, the use of one or two pairs of pinch rolls is recommended.[9] They contact the axis of the ingot on both sides and on opening they move forward. These should be arranged as overhung rolls to hold the ingot with continuous and uniform pressure.

With heavy sections these cannot be used; two, three, or more double-sided roll pairs must be provided. These have fixed rolls on one side and moving pressure rolls on the other.

For single and two-strand installations, as well as for multi-strand plants, working with small castings and in which, because of this, moulds and flying pinch rolls can be assembled tightly together in series, the plant can be divided vertically into a ' cold ' and a ' hot ' side.[10]

## References

1. K. G. Speith and A. Bungeroth: *Stahl Eisen*, 1952, vol. 72, pp. 869–885.
2. K. G. Speith and A. Bungeroth: *Ibid.*, 1956, vol. 76, pp. 427–442.
3. H. Kosmider, H. Neuhaus, and A. Weyel: *Ibid.*, pp. 668–678.
4. L. H. Nelson: *Trans. A.I.M.E.*, 1937, vol. 125, pp. 401–410.
5. H. Klein: *Giesserei techn. wiss. Beitr.*, 1953, No. 10, pp. 441–454.
6. F. G. Jaicks, L. E. Kraay, and W. Tenenbaum: *Trans. A.I.M.E.*, 1957, vol. 209, pp. 1057–1072; *J. Met.*, vol. 9.
7. C. I. Kozlitin and L. N. Kolyibalov: *Stal*, 1957, No. 3.
8. K. G. Speith and A. Bungeroth: *Forschungsberichte des Wirtschafts- und Werkehrsministeriums Nordrhein-Westfalen*, Ber. No. 234.
9. Austrian Patent No. 175,347.
10. J. Hofmayer: *Stahl Eisen*, 1957, vol. 77, pp. 69–78.

# Control of Flow of Liquid Metal During Continuous Casting

*By W. Siegfried and B. Broniewski*

SYNOPSIS

**This paper describes an electromagnetic method of controlling the supply of liquid steel in a continuous-casting installation in a mill designed to produce welding rod. After a brief reference to magnetic pumps now available with (*a*) the pump connected directly to the electricity supply and (*b*) with operation on induced electric current, the author describes the principle of an installation developed at the Battelle Institute, Geneva.**

**Some of the technical problems of choice of materials, cooling of the magnet iron and coils without overcooling the steel itself, and the arrangement of the magnetic circuit are reviewed.** 1615

PRECISION CONTROL PROBLEMS are extremely important in continuous casting. While it may be relatively easy to control the flow of metals of low melting point, it becomes more difficult with metals of higher melting points. Several current methods of controlling the continuous casting of metal are considered in Table I.

The work described in this paper was to develop a procedure permitting the flow of liquid steel passing through a 'rolling mill' making welding rods. As can be seen in Fig. 1, the system consists of several rolls profiled to give the required form of rod. Such a system raises problems of precision control additional to those posed by the continuous casting process. This control depends on the following factors: to obtain a steel rod of satisfactory quality, turbulence must be set up in the pool of metal in the basin formed by the rolls, and is only possible if the pool is kept sufficiently deep; if the level is too high, the liquid steel may overflow, possibly leading to a breakdown of the system. Moreover, care must be taken to see that the point of arrival of the liquid steel at the rolls is always the same.

After studying various methods controlling the flow of liquid steel, it was concluded that only an electromagnetic method could satisfy all the conditions imposed by the use of such a system.

### Electromagnetic Controls

*Magnetic Pump*—The principle of the magnetic pump is not new and it is available in a number of forms. Magnetic pumps fall into two broad classes: those with direct, and those with induced current supply.

*Direct-current Supply Pump*—In this pump, the liquid metal is directed by a magnetic field while a current traverses the metal at right-angles to the field. Such an installation is not always suitable except for metals with a melting point sufficiently low to prevent corrosion of the metals coming into contact with the liquid metal. With high melting-point metals it becomes essential to use oxidic materials for the parts in contact with liquid metals at high temperatures. In this case, an arrangement must be used in which the current is fed by metal electrodes, usually cooled.

*Inducing Current in Liquid Metal*—In a simple example of a pump operating on this principle, the metal to be pumped is in a cylindrical tube surrounded by a coil like that of an asynchronous motor. Inside the tube are laminations for conducting the magnetic flux. Such a system generates Foucault currents in the liquid metal, similar to those created in the short-circuited rotor of an asynchronous motor. They set up circulatory movements in the liquid metal, and by spiral vanes, the motion is converted into a rectilinear motion parallel to the tube axis, giving a pumping effect.

In another application for pumping liquid metal out of a melting furnace, induction produces very strong electric currents, which circulate inside the magnetic field and increase pressure by a magnetostriction.

Induced currents are also used to produce this pumping effect. They set up a magnetic field which moves parallel to the axis of a tube filled with liquid metal, and eddy currents set up by the magnetic field produce forces parallel to the tube axis. In such an arrangement, vanes for transforming the direction of motion of the liquid metal are unnecessary. In yet another principle, a polyphase winding surrounds the channel filled with metal, eddy currents induced in the metal by one of the phases co-operate with the magnetic flux created by another phase, and this co-operation creates forces parallel to the channel. They are zero at the middle of the channel.

After a critical examination, it was concluded that none of these installations was suitable for controlling the flow of liquid steel. Hence a special installation was designed and developed.

### Alternative Principle

The first task was to decide the principles of the new installation, with the following considerations:

(i) Materials for the tubes to contain the metal should not be attacked or dissolved by liquid steel during prolonged service at temperatures around 1600–1700° C. Liquid metal flowing through this tube should not be cooled if any increase in viscosity is to be avoided, and cooling will depend directly on the rate of flow: the lower it is, the greater the cooling. This is extremely important in controlling a spherical roller system where the flow-rate is necessarily small.

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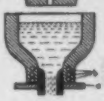
This is a slightly abridged version of the paper presented at the 10th Technical Session in Charleroi of the Journées Internationales de Sidérurgie.

The authors are with the Battelle Memorial Institute, Geneva, Switzerland.

**Table I**

**METHODS OF CONTROL IN CONTINUOUS CASTING**

| No. | Possible Method | Sketch of Principle | Disadvantages |
|---|---|---|---|
| 1 | Decantation of crucible | | At low flow-rates, metal solidifies near the spout and does not fall exactly between the rollers |
| 2 | Use of stopper rod | | Wear of refractory material occurs after prolonged use. Automatic control seems impossible |
| 3 | Cooling nozzle by (a) water-circulation cooling (b) high-frequency coil |  | Control would be too sluggish |

(ii) The temperature of iron in the magnetic circuit should not exceed the Curie point, or the iron will demagnetize and the pump will cease to function. This is contrary to the requirement that the steel should not be cooled. Hence it has been necessary to use special devices for satisfying these two opposing conditions.

(iii) Materials which resist attack by liquid steel are very sensitive to thermal stresses. A procedure must therefore be found for preheating parts made of such materials before they are put into service, to avoid destruction by thermal shock when they come into contact with liquid steel. The danger of cracking depends on the material itself and the shape of the tube and will increase with the size and complication of the parts affected. Hence the shape of ceramic parts should be as simple as possible.

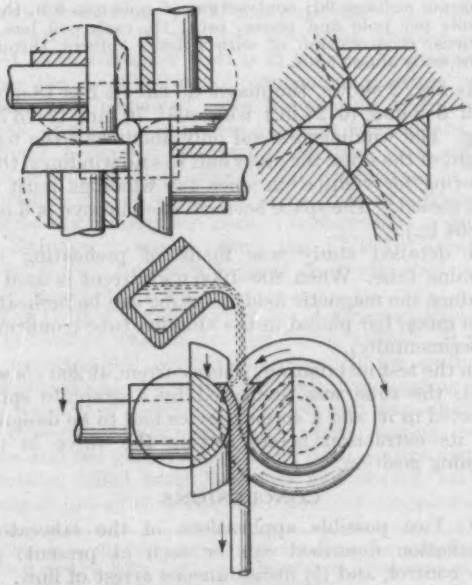


**Fig. 1—Arrangement of rolls in mill**

**Table II**

**CONTROL PRINCIPLES CONSIDERED**

| Current | Principle | Reference | Possibilities of Application to Pumping Liquid Metals |
|---|---|---|---|
| Direct feed | Tube for metal is a conductor, e.g. liquid Na in stainless-steel tube | Mech. Eng. June 1953 | Only to metals of very low melting point |
| A.c. induced in metal | Tube for metal is not a conductor. Current supplied by cooled electrodes | U.S. Patent no. 2,743,492 | Cannot be used for steel because of complexity of ceramic segments |
| ,, | Liquid metal, as it were, forms transformer secondary. Current produced causes circulation (Ajax pump). Rotary motion converted to linear by baffle system | U.S. Patent no. 2,707,718 | Cannot be used for steel because of high temperature |
| | Moving magnetic field is produced as for an asynchronous motor. Rotary motion converted to linear by vanes | Mech. Eng. June 1953 | Too complicated for steel |
| ,, | Magnetic (linear) field moves parallel to tube axis | U.S. Patent no. 2,764,095 | Only procedure capable of further development for steel |
| | Control with a polyphase winding around the tube through which metal flows | French Patent no. 1,083,613 | Braking effect less efficient than in preceding example; braking point in middle of tube |

(iv) Since the density of iron is fairly high, the magnetic field created should be very powerful to give a satisfactory pumping effect. Thus the air gap should be as small as feasible, although this requirement does not harmonize with (ii) and (iii) above.

(v) Operational reliability of such an installation should be very high Any possible breakage of a ceramic tube should not cause danger to the installation as a whole.

### Choice of Materials

The most suitable material for constructing the apparatus required would be an electrical conductor immune to attack by liquid steel.

A systematic review of materials available was made, including some new intermetallic compounds, e.g. zirconium boride, molybdenum disilicide, tungsten boride and disilicide, chromium boride, molybdenum carbide, tungsten carbide. Test plates produced by hot pressing were immersed for definite periods in liquid steel, but at 1800° C all were rapidly attacked, which was sufficient reason for rejecting the idea of using intermetallic compounds.

Similar tests made with materials such as oxides and ceramics revealed the excellent behaviour of sintered alumina, even ofter prolonged contact with liquid steel.

### Determination of Control Principle

To find out the principle of control best suited to the problem, comparisons were made between control by direct feed of current and control with a moving magnetic field. The results are given in Table II. The use of an installation with cooled electrodes raises such difficulties, and the losses of heat from the

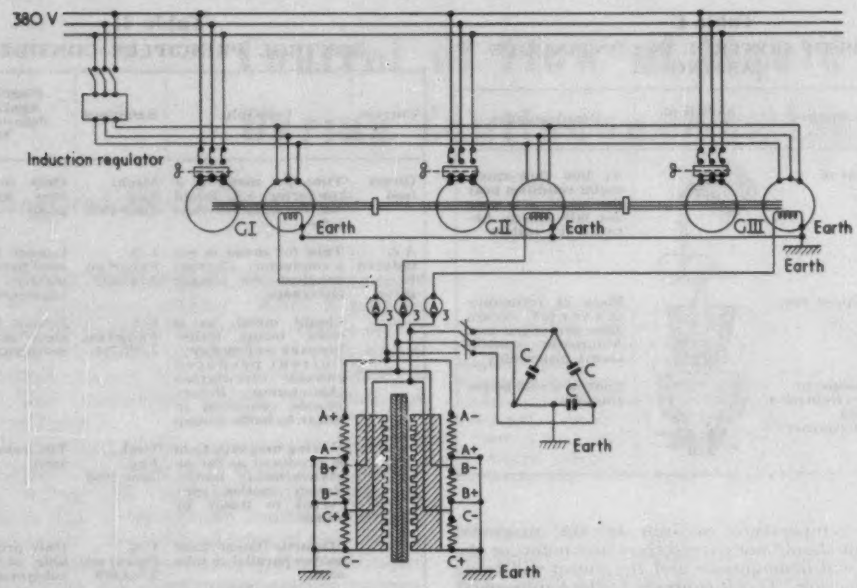



**Fig. 2—Circuit diagram for current supply to 200 c/s induction pump**

contacts are so high, that preference is given to an installation based on the principle of the moving magnetic field, moving parallel to the tube axis. The special problems posed by flow control of liquid steel were solved as follows.

The greatest problem consisted in adequately cooling the iron in the magnetic circuit and the electric coils without overcooling the steel itself. This was achieved by cooling the magnetic iron and the coils with a very powerful current of air. At the same time, heat losses from the tube were balanced by electrical heating. In this way loss of heat from the liquid metal is avoided. When the frequency of the magnetic field reaches a certain level, the rate of heat generation by eddy currents is sufficient to balance heat losses due to cooling. Preliminary studies under variable frequency showed 800–1000 c/s to be the necessary current.

Since in the laboratory only three-phase 200 c/s current was available, this resistance heating in the prototype was added to balance heat losses due to cooling. In an inconel tube, an internal tube in which the steel is cast consists of sintered alumina elements jointed with a refractory cement. To prevent the propagation of any fissuring along the whole length of the tube, it was considered necessary to make it in several sections, and the tube itself was placed inside a second inconel tube, about 2 mm wider. The space between the inconel tube and the sintered alumina tube was filled with an alumina cement, to serve as insulation. Electrodes which supply heating current are fixed at the ends of the inconel tube. The tube is also provided with horizontal slits to increase the electrical resistance and also to prevent weakening of the magnetic field inside the metal itself, which could arise through the generation of eddy currents. The rammed cement in the space between the two tubes acts as thermal insulation, so that it is possible to heat the inconel tube to 1100–1200° C to prevent cooling of the liquid steel flowing therein; also, it increases operational reliability. If the tube cracks, thus allowing steel to leak out, there will be a self-sealing sintering at the point of leakage. This installation has proved perfectly satisfactorily in the tests carried out.

### Magnetic Circuit

The circuit diagram of the prototype is shown in Fig. 2. The winding characteristics are as follows:

> Three-phase supply at 200 c/s in star connection; simple voltage 60; contraction of pole gap 8/9; three coils per pole and phase, total 18, each coil has 10 turns; cross-section of wire 1 mm²; current through the coils about 50 A.

As Fig. 2 shows, the magnetic circuit has 18 slots, each 6·5 mm (0·26 in.) wide and 70 mm (2·75 in.) long. The windings extend only about half the total height of the slots; the other half has no windings, thus allowing for ventilation since the windings must be well cooled. The space between each groove is 5 mm (13/64 in.).

A detailed study was made of preheating the alumina tube. When 800–1000 c/s current is used to produce the magnetic field, the tube can be preheated by a metal bar placed in the alumina tube (confirmed experimentally).

In the test installation, where current at 200 c/s was used, the tube was preheated by a graphite spiral inserted in it, and a special device had to be designed for its extraction before setting the valve in the running position.

## CONCLUSIONS

(1) Two possible applications of the laboratory installation described can be seen at present: (*a*) flow control, and (*b*) instantaneous arrest of flow. In (*b*), the formation of droplets has been observed with

several metals, and the installation in its present form is incapable of retaining these, thus making complete stoppage of flow impossible. To surmount this, further design refinements will be necessary. Drops form through the operation of various factors, e.g. surface tension of the metal, wettability of the refractory material of the tube with liquid steel, and size of the grooves. As an example, the flow of aluminium in a tube 1·5 m (about 5 ft) long can be sharply arrested by the design in its present form.

(2) It is possible to obtain an accurate height of flow control corresponding to 35 mm Hg. It is permissible to accelerate the process in the installation to attain double this height for flow control, and these values could possibly be increased still more.

(3) In practice, control of flow of liquid steel requires frequencies of several kc/s. It is obvious that in this case all the problems posed by heating (preheating) and by cooling the liquid metal would be solved in advance and would not create any operational difficulties. Further work is needed on absolute and instantaneous arrest of liquid steel flow.

# Continuous Casting

## AT THE CENTRE NATIONAL DE RECHERCHES METALLURGIQUES, SECTION DU HAINAUT, CHARLEROI, BELGIUM

*By J. Zaeytydt*

SYNOPSIS

**The author describes the experimental installation of the CNRM built at the Aciéries et Minières de la Sambre during 1956–1957, the first unit of which went into production in December 1957. It is intended to test the layout and to study the casting conditions for ingots of killed basic Bessemer and electric carbon or low-alloy steels of 3–5-in. square section. A second unit now under construction will serve for studying the casting of rimming basic Bessemer steel ingots from 4·72 to 8-in. square section, and 4·72 to 13·8-in. slabs.** 1616

### INTRODUCTION

IN 1953 the National Metallurgical Research Centre published a review of continuous casting, including foreign developments in this field.

At this period, continuous casting of special steels and plain steels was well under way, and prospects opened up for steels made in open-hearth and electric furnaces of capacity smaller than 30 tons, which, with rare exceptions, were typical of Belgian installations. But 85% of Belgian steel is produced in basic Bessemer converters of 15–30 tons capacity at the rate of one cast every 30 min per converter blowing, and most basic Bessemer steel is of the rimming variety. Here the possibilities of continuous casting were much more restricted since the casting of rimming steels appeared, from experiments abroad, to be difficult to apply to sections of less than $4\frac{3}{4}$-in. square section, thus limiting the application of the procedure to the economic production of billets for small-section merchant bars. Consequently, a group of Hainaut factories asked the CNRM (National Metallurgical Research Centre) to study their continuous casting problems.

The CNRM installation at the Aciéries et Minières de la Sambre was constructed during 1956–7. It was an experimental installation intended for studying equipment and procedures for continuous casting and the training of personnel. The first unit was intended for developing equipment, and studying casting conditions and the properties of 3 and 5 in. square-section ingots in killed basic Bessemer and electric carbon steels or low-alloy steels. The unit was commissioned in December 1957 and has a 3·55 in. square-section mould with a resilient mounting on the principle developed by B.I.S.R.A.

At present a second unit is being constructed for studying the casting of rimming basic Bessemer steel ingots of 4·72 in. to about 8 in. square section, and slabs measuring 4·72 in. × 13·8 in.

### EXPERIMENTAL INSTALLATION

The experimental CNRM installation is intended for studying continuous casting of basic Bessemer and electric steels made in converters or furnaces of 15–20 tons capacity and is situated near the basic and electric steelworks. The casting ladle is brought to the converter on a truck by the steelworks gantry crane, and is then transferred to the continuous casting building.

Before casting, the ladle is preheated on the transfer truck in the continuous casting building, the duration of transfer and filling from the time the preheated ladle leaves for the steelworks to the start of continuous casting is about 8 min.

The height of the installation (82 ft) made it possible to start a study of casting ingots the depth of whose liquid zone can in principle attain 26·25 ft. The maximum cut-off length is 18·4 ft.

The tower is intended for four units, but at present only one is used for producing 3·55 in. square-section

This is a slightly abridged version of the paper presented at the 10th Technical Session in Charleroi of the Journées Internationales de Sidérurgie.

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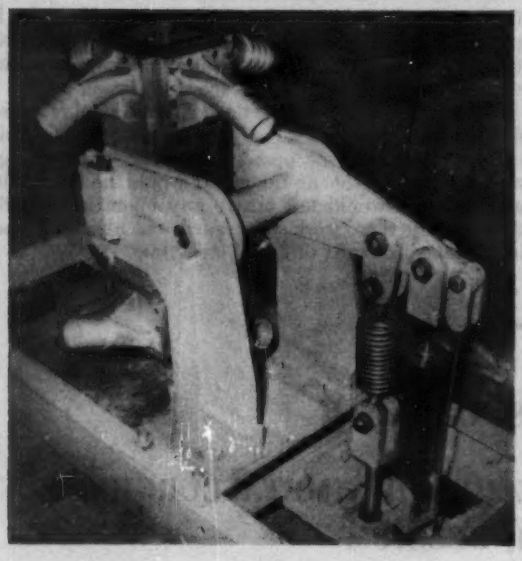

Fig. 1—Mould mounting

ingots; a second unit for 8 in. square-section ingots is being constructed. Equipment for the casting tower was made in the CNRM workshop. The mould is of 0·8-in. thick copper plates screwed together. It has an internal section 3·55 in. square, and the mould is 21·65 in. long.

The mould faces are cooled separately, the corners are not. This ensures perfect tightness and a fairly uniform cooling of the metal over the whole periphery of the mould. The aluminium-alloy heads provide a progressive transition from circular section at the inlet and outlet ends to the rectangular section of the wall. The maximum flow of water, 3180 ft³/h, corresponds to a linear flow rate of water of 32·8 ft/s.

The mould can move vertically with an amplitude of about 4 in. and is supported by two trunnions at the end of an equal-arm lever. At the other end of the lever there is a spring of suitable modulus. The arrangement can also be provided with a damping system braking the ascent of the mould, and counterweighting (Fig. 1). Rapeseed oil lubrication is provided through oilways in the side.

When the ingot leaves the mould it is guided by an arrangement of 14 cast-iron rollers, 3 in. dia., in orthogonal pairs, over a distance of about 24 in. After this series of closely spaced rollers, the ingot is guided by 11 pairs of 6-in. dia. rollers over a distance of about 16·4 ft. All the rollers turn on fixed hollow axles, and cooling is provided for. The ingot is guided under the extractor and kept at a constant distance from the tip of the cutting torch by three pairs of 3-in. dia. rolls. No cooling is provided. The guide rollers are shown in Figs. 2–4. The dummy bar introduced into the mould at the start of casting is supported by a false ingot of two bars respectively 14·4 and 14·8 ft long.

The extraction equipment consists of a pair of steel pinch rolls, a speed reducer, a hydraulic speed variator, and an electric motor of about 3½ h.p. The equipment is controlled by a servomotor from the casting platform.

The gripping force is obtained with two helicoidal springs acting across the extractor jaws (Fig. 4). The amount of cooling required by the ingot when it leaves the mould depends on many factors, particularly the type of steel, the cross-section of the billet, the rate of movement, etc. At present simple rows of sprays are used, but later installation of water–compressed-air atomizers is possible. The secondary cooling water is collected in a tank above the extractor. Scale is retained by filters and in a compartment of the reservoir feeding the pumps.

The 3·55 in. square-section ingot is cut automatically into fixed lengths of 14·75 ft by a gas cutter. For low-carbon steels, only town gas and oxygen are used. The cutter is moved with an oleo-pneumatic cylinder, and the nozzle of the cutter describes an arc. The electromagnetic valves in the gas and oxygen circuits are opened and closed by manually controlled switches. An electronic time-switch controls the duration of preheating.

The gas flame cuts the ingot during its descent, an operation which requires perfect synchronization of the descent of billet and cutter. This is obtained by mounting the cutter on a bracket solid with the cradle which receives the ingot. This cradle is mounted on a framework 19·75 ft long, sliding in vertical guides, and suspended by cables and pulleys and counterweighted so that it ascends again when unloaded. During gas-cutting the ingot pushes the framework and synchronization of billet and gas-cutter movements is perfect. When the ingot is cut, or when the first section of the false ingot is unclamped, the framework drops slowly downwards.

At the bottom position, the cradle tilts and the ingot is conveyed by rolls to the cooling bay. Movement of the cradle is by an oleo-pneumatic cylinder automatically controlled by cams acting on pilot valves and pneumatic relays.

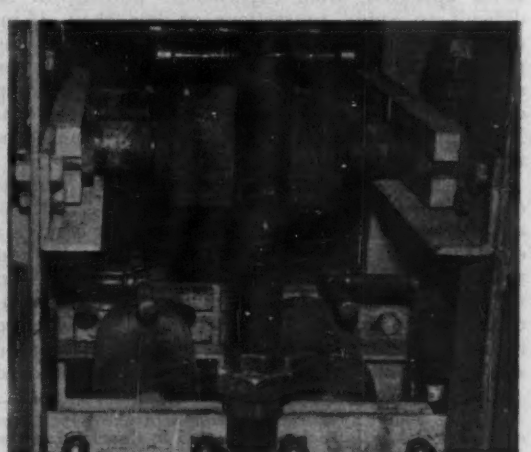

Fig. 2—6-in. rollers and cooling nozzles

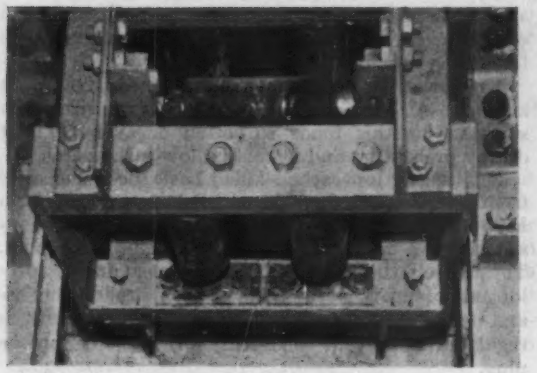

Fig. 3—3-in. guide rollers beneath pinch rolls

### Casting 3·55-in. Square-section Ingots

With killed basic Bessemer, plain, and low-alloy steels, simple calculation shows that four ingots of 3·55 in. square section must be extracted at the mean rate of 6·15 ft/min to empty the contents of a 20-ton ladle in 45 min. Another point is that this speed must be attainable and that it must be compatible with the required quality criteria for the ingot.

The first strand for the 3·55-in. square section was built to study the means by which optimum casting speed can be attained for a given type of steel. For the first studies intended mainly to find out the mechanical behaviour of the installation, a basic Bessemer steel poured at the converter into a 2-ton ladle and killed in the ladle with silico-calcium was used.

Table I shows the liquidus and solidus temperatures of three plain steels. The killed low-carbon basic Bessemer steel is an interesting case to study from the viewpoint of the thermal conditions to be realized for preventing solidification in the ladle and in the casting tundish.

Single-unit operation prevented the use of the 20-ton teeming ladle used at the steelworks, since this would

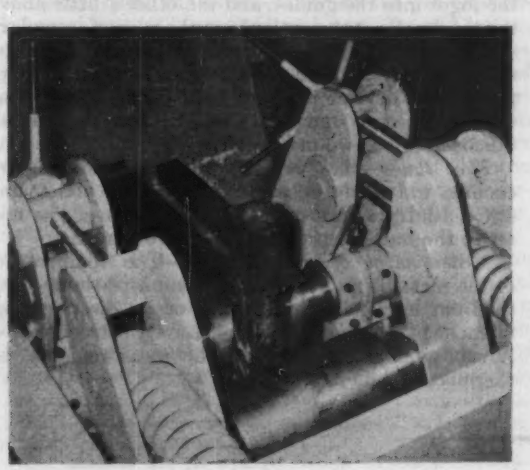

Fig. 4—Close-up of pinch rolls

Table I

LIQUIDUS AND SOLIDUS TEMPERATURES OF THREE PLAIN STEELS

| Carbon, % | Liquidus Temperature, °C | Solidus Temperature, °C |
|---|---|---|
| 0·1 | 1528 | 1528 |
| 0·5 | 1480 | 1400 |
| 1·0 | 1450 | 1230 |

have necessitated attaining a pouring rate of 23 ft/min. The solution of casting simultaneously into a continuous-casting mould and several conventional moulds, then finishing the cast by conventional methods, was also abandoned.

### CASTING LADLE

It was decided to use during the period of strand development a teapot ladle of about 2 tons capacity; tests were also made with a bottom-stoppered ladle of similar capacity. The first teapot ladles were made with the spout outside the shell; the shell of the ladle was then rammed and the outside spout replaced by a channel in the rammed lining. The partition wall of the spout at the inner end of the lining was of sillimanite bricks and the lining was rammed pneumatically with Charleroi sand as used for steelworks ladles.

The bottom of the ladle was rammed and the sillimanite bricks for the spout partition wall were sealed in the sand. A plumbago cement was used for making certain joints at the bottom of the spout where erosion is particularly strong.

This ladle is considerably more convenient than one with an external spout, from the viewpoints of construction and maintenance, and of heat losses from the spout. The level of metal in the tundish is easily controlled, whereas the same control with a stopper ladle requires a series of openings and closings of the nozzle. The wear of the nozzle can more or less compensate the decrease in ferrostatic pressure in the ladle during casting; other solutions have, however, been proposed, such as the use of superimposed nozzles which can be extracted during casting. The use of a stopper ladle requires certain precautions during transfer to avoid leaking of steel through the nozzle if the stopper is defective, one solution being to introduce a dry-sand plug into the nozzle, the sand being kept in place by a steel plate which is removed at the instant of casting.

The teapot ladle may also be preheated more than the stopper ladle, which is important with small ladles which must be preheated to a high temperature. A teapot ladle of about 2-tons capacity can be preheated to 1400° C without inconvenience, whereas it has been found inadvisable to heat a similar stopper ladle above 900° C; beyond this temperature the stopper rod does not behave satisfactorily over a prolonged period.

In the final stage of the study, it is intended to use a stopper ladle of about 20-tons capacity, so as to use the conventional steelworks ladle. The use of a similar teapot ladle would necessitate the construction of a considerably stronger pouring cradle and metal framework for the tower.

The 2-ton ladle is preheated on the transfer truck in the continuous casting building. The ladle placed in its normal position is covered with a lid of refractory bricks with a hole on which is fitted a premixing burner of 1050 $ft^3/h$ capacity operating on gas of 4250 $kgcal/m^3$ calorific value. The burned gases escape at the bottom of the ladle and ascend through the spout hole.

The ladle is dried after ramming for 24–48 h; preheating lasts about 6 h. The spout is brought to more than 1200° C in 4 h and kept between 1200° and 1300° C for the last 2 h before casting. The temperature inside the shell is about 1400° C. Before shutting off the burner, the lid is removed and replaced by a steel cover to limit radiation loss of heat from the ladle during transport to the converter. The cover is removed for filling at the converter and is replaced when the filled ladle is lowered on the transfer truck.

Conditions for preheating the ladle and superheating the steel were determined by a series of casting tests at ground level on conventional ingot moulds placed under the tundish.

The temperature of the steel at the end of the blow should be 1640–1660° C. This is measured with an immersion pyrometer before ferro-manganese addition. Silico-calcium is added to the ladle during filling, the temperature after filling is about 1610° C. The metal stays in the ladle 30–40 min. The temperature of the steel measured in the tundish is 1540–1560° C. No tendency to skulling in the ladle has been observed under the above conditions.

### Tundish

The function of this is to control and stop casting, to ensure that the steel jet is perfectly centred in the mould, and to limit the entrainment of slag by the metal and to promote separation of inclusions.

Initially, it was intended to use a tundish pouring metal through a spout; meanwhile Pritchard at B.I.S.R.A. developed a tundish with a heated nozzle so that a tundish operating on this principle but modified and adapted to the conditions in a basic Bessemer steelworks is now used. The units of the tundish are preheated separately by suitable burners. The lining is rammed, its volume being reduced enough to ensure sufficiently rapid renewal of the steel during casting. The head of the metal in the tundish is about 6 in. and the ferrostatic head measured from the end of the bottom nozzle is about 14 in.

The nozzle unit consists of a cut-off nozzle, closed by the stopper rod. It is made in silico-alumina material of 40–42% alumina about 1 in. dia. Under the cut-off nozzle there is a metering nozzle for delivering the mean flow desired. This can be calculated with a good approximation by the relation $G = d^2h^{\frac{1}{2}}/4$, where $G$ is the flow in kg/s, $d$ is the diameter of the nozzle in cm, and $h$ is the ferrostatic head in cm.

The cut-off nozzle and the nozzle delivering the desired flow are located in a supporting tube of a material with a good resistance to thermal shock, a good thermal conductivity, good strength, and good oxidation resistance. Carborundum and plumbago have been found suitable.

The lower nozzle which fixes the mean flow is in zirconia. Attempts have been made to use zirconium silicate, but this tends to soften or even to melt during preheating and in casting low-carbon steels.

For casting low-carbon killed basic Bessemer steel from the 2-ton ladle, the tundish is preheated to 1500° C and the nozzle to 1530° C. The stopper consists of two fireclay sleeves and a plumbago plug. To protect the stem of the stopper during prolonged preheating to 1500° C it is made hollow and is air-cooled. The flow of air through it is regulated to prevent solidification of the steel on the plug.

Under conditions described, it is possible to cast low-carbon killed basic Bessemer steel for 20–30 min through nozzles of 0·36–0·47 in. dia.

### Measuring Equipment

*Pouring Rate*—This is measured with a dynamo tachometer connected to the output shaft of the speed variator. The pouring rate is recorded and reproduced by indicators on the control desk and at the gas-cutter control platform.

*Mould Friction and Adhesion Forces*—These forces are proportional to the elongation of the spring acting at the extremity of the lever supporting the mould and described earlier. A potentiometric arrangement permits recordings of movements which are easily transformed into forces by calibration. The pouring rate and the frictional and adhesional forces are recorded simultaneously with a two-pen recorder.

*Measurement of Gripping Force Exerted on Ingot*—This is proportional to the compression of the springs on the pinch rolls. The force exerted by each of these springs is detected by a potentiometric transducer and transmitted to an indicating apparatus.

*Measurement of Secondary Cooling on Ingot*—Surface temperature of the ingot is measured at two points, one underneath the mould before the entry of the ingot into the guides, and the other a little above the pinch rolls at the outlet from the zone of secondary spray cooling. The measuring elements are total radiation water-cooled pyrometers. A slight positive pressure of dry air is maintained inside the sighting tube. The two temperatures are recorded simultaneously by a two-pen recorder.

*Flow Rates*—Flow rates of primary and secondary cooling water are measured by orifice plates and differential pressure gauges. Flow rates of gas and air to the burners are indicated by rotameters.

*Measurement of Temperatures*—The temperature of the metal is measured by platinum/platinum–13% rhodium immersion pyrometers or by disappearing-filament pyrometers with an emissivity correction 0·4. A six-point recorder permits measurements by thermocouple as required.

# A Theory of Decarburization by Scale

*By K. Sachs and J. R. Brown*

SYNOPSIS

**Reaction between carbon in the steel and scale on the surface can decarburize the steel only if the gaseous products of the reaction can escape through the scale. The conditions likely to cause rupture of of the scale and thus initiate decarburization are considered qualitatively.** 1478a

BY SUITABLE CONTROL of the heat-treatment conditions, steels can be either carburized or decarburized in atmospheres which may be oxidizing or reducing to the steel itself. Experience has shown that decarburization is exceptionally rapid and severe in atmospheres intended to suppress scale formation.[1] At the other extreme, rapid scaling in severely oxidizing atmospheres can prevent decarburization altogether.[2,3]

Consideration of recently published experiments[4] shows that decarburization proceeds more slowly in the presence of scale, so that its apparent suppression is not due primarily to the more rapid competitive process of oxidation. A steel containing 0·7% C (and incidentally 0·38% Cu) was heated in air and argon at 1200° C. The dimensions of the specimens were 25 mm × 25 mm × 40 mm and in the argon treatment decarburization was complete in 2 h; a similar treatment in air produced a ferrite layer 0·2 mm thick and a scale layer 0·5 mm thick. It appears that scale inhibits decarburization, rather than forestalling it. In fact, the presence of a scale layer may suppress decarburization to such an extent that the carbon from the oxidized layer is forced back into the receding steel surface, leading to build-up of carbon under oxidizing conditions. Carbon enrichment at the surface has been observed in medium- and high-carbon steels heated in severely oxidizing atmospheres.[5]

The oxidation of various binary alloys containing carbon as the second component has been considered by Webb, Norton, and Wagner.[6] The pressures of CO and $CO_2$ in equilibrium with the oxide of the major component were estimated from thermodynamic data; in the Ni–C system the equilibrium pressure is high and experiments showed that nickel is decarburized; in the Mn–C system the gas pressure is low, the metal is oxidized preferentially, and carbon diffuses back into the bulk metal. The authors postulate that a compact scale prevents access of oxygen in the atmosphere to the surface so that decarburization cannot take place. The carbon reacts with the oxide, forming CO and $CO_2$ at the equilibrium pressure; if this pressure disrupts the scale, oxygen can reach the atmosphere and decarburization can proceed; if the scale resists the pressure, no further reaction takes place.

It is our object in this note to put forward the suggestion that the same mechanism plays an important part in the oxidation of steel. It has been shown that when a scale layer grows on steel decarburization is usually observed, but carbon build-up may occur in special circumstances. This would imply that the mechanical strength of the scale is roughly similar to the equilibrium pressure of CO and $CO_2$, a little lower in the case of decarburization, a little higher for carbon build-up. The equilibrium pressure of the gases can be estimated from thermodynamic data[7]; for example, at 900° C, austenite containing 1% C would be in equilibrium with FeO at a CO pressure of 15 atm and a $CO_2$ pressure of 8 atm; at 1000° C the corresponding equilibrium pressures would be 30 and 15 atm respectively. No figures are available for the rupture strength of scale on steels at these temperatures; in recent experiments on the adhesion of scale to the steel surface at room temperature,[8] a few samples failed within the scale layer at a stress of 80 kg/mm². It seems quite possible that the rupture strength might decrease to 40 or 50 kg/mm² (1 kg/mm² = 1 atm) between room temperature and 1000° C. It looks as though the equilibrium pressure and the cohesion strength of the scale are roughly similar at high temperatures. In the case of a small pore in a thick scale, the circumferential stress is equal to the internal pressure, so that in this temperature range the equilibrium pressure of carbon-bearing gases may be high enough to burst open the scale.

The experimental evidence on carbon build-up[5] indicates that it reaches a maximum in the first hour of the oxidation treatment; from then on, the carbon content of the surface layer diminishes and, when the original carbon content of the steel is passed, decarburization proper sets in. In the German experiments on decarburization referred to above,[4] the thickness of the ferrite layer was measured after heating in air at 900°, 1000°, and 1200°C for various periods; extrapolation backwards suggests that no decarburization has occurred in the first hour. It is possible that carbon build-up occurs quite frequently in the early stages of oxidation of a carbon steel, presumably while a compact scale layer is growing, and that decarburization takes the place of carbon build-up only after mechanical rupture of the scale has occurred; this change in the mechanism of oxidation in the course of the treatment should be reflected in the kinetics of oxide growth.

When a carbon steel is heated in an oxidizing atmosphere a compact scale is formed in a relatively short time. Oxidation continues at a parabolic rate and while the scale remains compact decarburization is suppressed. After some time mechanical rupture of the oxide occurs, the scale is no longer compact, oxidation proceeds at a higher rate (although it may still be parabolic owing to intermittent healing of the

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oxide layer), and decarburization sets in. This mechanism implies that in the initial 'compact layer' stage the rupture strength of the scale is higher than the equilibrium pressure of carbon-bearing gases and that some time later the equilibrium pressure exceeds the mechanical strength. It is conceivable, but not very likely, that the mechanical strength of the oxide diminishes progressively as the scale grows; it is widely believed that the scale layer is stressed and that the internal stress increases with thickness—some exfoliation phenomena have been explained in this way—and it is quite possible that a gradual increase in internal stress, together with the equilibrium pressure of carbonaceous gases, will lead to rupture of the oxide. Moreover, there is a progressive rise in equilibrium pressure. Accumulation of carbon at the surface of the steel will increase the carbon activity and therefore the equilibrium pressure. Increasing the carbon from 1·0% to 1·1% would increase the pressure by about 10%.

The volume change associated with the oxidation of iron will influence the gas pressures. Even in a perfect scale, the reaction $FeO + C \rightleftharpoons Fe + CO$ will lead to a shrinkage in total volume, so that space becomes available to accommodate the CO formed. Calculation shows that if gram-equivalent weights are involved in the reaction the volume of oxide which dissociates is $72/5·8 = 12·4$ cm³, while the volume of iron reduced is $56/7·8 = 7·2$ cm³, leaving $5·2$ cm³ to be occupied by 1 g-mol of CO; at 1 atm this amount of CO would occupy 22,400 cm³ so that the pressure in the newly formed space would be 4300 atm; for $CO_2$ the pressure is 2150 atm. These values are far in excess of the equilibrium pressures, so that the reaction would proceed in the reverse direction.

Scales may contain pores filled with oxygen at the dissociation pressure of the oxide around them[9, 10, 11]; as the scale thickens the total volume of porosity increases and it may eventually be able to accommodate the carbon-bearing gases at pressures below the equilibrium value for decarburization. From then on, decarburization could proceed at a rate controlled by the growth of the pores in the scale even without mechanical rupture of the oxide layer; clearly, if decarburization is controlled by the rate of oxidation, it is likely to be so slow as to be barely detectable in oxidized specimens. Alternatively, the pores could serve as nuclei for the formation of carbonaceous gases which may lead to mechanical rupture of the scale.

These considerations are based on the simplifying assumption that the oxide itself is completely impermeable to carbon. Slow diffusion of carbon through the oxide, and indeed some measure of solubility of carbon in the oxide, is a possibility which deserves some consideration. Unless diffusion through the scale is fast enough to provide an independent mechanism of decarburization, it would not interfere with initial carbon build-up followed by mechanical rupture of the scale leading to direct decarburization by the atmosphere. On the other hand, diffusion would help to explain how equilibrium can be maintained between the carbon activity at the surface of the steel and the pressure of carbonaceous gases in the pores of the scale.

Discontinuities at the interface itself can, of course, be filled with CO and $CO_2$ at equilibrium pressures, but continued oxidation means that an oxide layer must form on the exposed metal surface of any discontinuity. Any pore in the scale will contain oxygen at the dissociation pressure of the surrounding oxide; since there is an oxygen-concentration gradient across the thickness of the scale, the dissociation pressure will be higher at the outer than at the inner wall and oxygen will tend to dissociate from the former and join the oxide at the latter. It follows that discontinuities at the interface must eventually become separated from the metal by a thickening membrane of oxide and the carbon activity equilibrium can only be maintained if carbon can diffuse through this membrane.

In the general case of initial carbon build-up followed by decarburization, the onset of decarburization may be determined by the thickness of the scale, if internal stress in the oxide layer together with the equilibrium gas pressure ruptures the scale; by the carbon content reached at the surface of the steel, if the increase in equilibrium pressure due to the carbon activity is the decisive factor; by the appearance of a critical volume of porosity in the scale, if nucleation of the formation of the carbonaceous gases is necessary to initiate decarburization or rupture of the scale; or by the slow build-up of pressure in the pores due to the slow diffusion of carbon through the oxide.

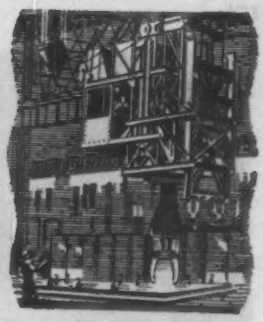
When mechanical rupture of the scale occurs, the carbon-bearing gases can escape and decarburization can proceed rapidly. The atmosphere can gain access to the metal and oxidation is speeded up. Continuing oxidation will tend to heal the oxide layer, but, as soon as the escape of carbon-bearing gases is prevented, their pressure will rise again, until they break through once more. Oxidation will proceed by repeated cycles of rupture and healing of the scale, and will tend to settle down to a parabolic rate which is slightly higher than that prevailing in the previous 'compact scale' stage. Decarburization will proceed in regular bursts, but after a while diffusion of carbon through the decarburized layer will become the controlling rate and decarburization also will follow a parabolic law.

## References


1. D. K. Bullens *et al.*: "Steel and its Heat Treatment," 1948, vol. 2, p. 111.
2. *Ibid.*, p. 114.
3. J. V. Emmons: *Trans.A.I.M.E.*, 1914, vol. 50, pp. 405–423.
4. C. Eisenhuth, W. Gruhl, W. Papsdorf, and I. Eisenhuth: *Stahl Eisen*, 1957, vol. 77, pp. 357–359.
5. R. D. Stout and Toivo Aho: Symposium on Controlled Atmospheres, pp. 159–175: 1942, Cleveland, American Society for Metals.
6. W. W. Webb, J. T. Norton, and C. Wagner: *J. Electrochem. Soc.*, 1956, vol. 103, pp. 112–117.
7. F. D. Richardson and J. H. E. Jeffes: *J.I.S.I.*, 1948, vol. 160, pp 261–270; F. D. Richardson: *J.I.S.I.*, 1953, vol. 175, pp. 33–51.
8. H.-J. Engell and F. K. Peters: *Arch. Eisenhüt.*, 1957, vol. 28, pp. 567–574.
9. L. B. Pfeil: *J.I.S.I.*, 1929, vol. 119, pp. 501–547.
10. A. Dravnieks and H. J. McDonald: *J. Electrochem. Soc.*, 1948, vol. 94, pp. 139–150.
11. K. Sachs: *J.I.S.I.*, 1957, vol. 187, pp. 93–104.

*IRON AND STEELWORKS ENGINEERING*

**The Iron and Steel Engineers Group**



# The Ergonomic Aspects of the Design of Cranes

*By R. G. Sell, B.Sc., Dip. Psych.*

SYNOPSIS

**This report describes how cranes and crane cabs can be designed to suit the characteristics of the men who have to drive them. Methods are described by which the cab can be designed and sited on the crane structure to ensure good visibility. Recommendations are made for the protection of operators from the bad physical conditions prevailing in many steelworks buildings.**

**Details are given of the anthropometric seat developed by B.I.S.R.A. in conjunction with the Medical Research Council. Researches are described into the order and amount of use of crane controls and the positioning of crane controls, and it is shown how the information so obtained is used in the design of control points.**

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ERGONOMICS is the study of the relation between man and his working environment, particularly the application of anatomical, physiological, and psychological knowledge to the problems arising therefrom. It is the process of fitting the job to the man as opposed to fitting the man to the job. The ergonomic aspects of the design of a piece of equipment should always be considered before selecting and training operators to use it, because this enables a wider range of people to be used and reduces training time to a minimum.

When applied to the design of cranes, ergonomics has the effect of speeding up certain operations and of reducing the fatigue of the driver and thus reducing his liability to have accidents. In the past the tendency has been to consider the mechanical aspects of the design of equipment first and only to give attention to the operator as an afterthought.

Figure 1 shows a steelworks crane cab of traditional design, which indicates the lack of consideration given to the crane driver in the past. There is no provision for seating during normal working, and no protection from heat or dust. The controllers are awkwardly placed and have a difficult semicircular motion, and it is not easy to see out of the cab without leaning out.

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Mr. Sell is on the staff of the Division's Electrical Engineering Section.

This paper describes the researches carried out so far at B.I.S.R.A. on the subject and gives recommendations based on the general principles. It follows on from the previous report on this subject issued by B.I.S.R.A.[1]

## POSITION OF THE CRANE CAB

The crane cab has to be positioned so that the driver can see his hook at all times and as much of the shop as possible, so that he is away from any source of heat or noise, and so that access to it can be easily provided. All too often the cab is considered only as an appendage and due consideration is not given to its position and design until a late stage in designing the crane.

It is fairly easy to decide at the drawing-board stage where a cab should not go because of heat or noise, but it is not always so easy to decide where the best position is for maximum visibility.

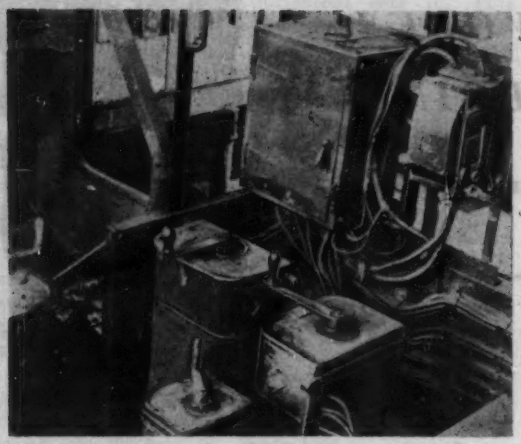

Fig. 1—Old-type crane cab

B.I.S.R.A. has recently carried out an investigation for a steelworks to find the best position for the cab on a rod-mill warehouse crane. To do this a model of the shop was built to a scale of $\frac{1}{4}$ in. to the foot including all likely obstacles to the driver's vision. A model was built of the structure of the crane, and a small electric bulb was arranged so that it could be hung under any part of the bridge. This bulb was always positioned, relative to the crane structure, in the place where the driver's head would be. This model is shown in Fig. 2.

By placing the model in the dark, lighting this bulb, and placing it in various positions, the shadows cast by obstructions in the shop showed which parts the driver would not be able to see if the cab were placed in that particular position on the crane. The hook was placed on a moveable 'crab' and was supported by a bar which could be locked in any position. Varying the position of the bulb and the hook together showed the best position for fixing the cab so that the driver could see the maximum working area and so that he could always see his hook during normal working. Special attention was paid to the pattern of work in this shop, as the crane nearly always picked up and dropped loads in certain areas and all loads had to be weighed. Visibility was always considered with the hook in these positions. As a result of the complete study a satisfactory position for the crane cab was arrived at.

## DESIGN OF THE CAB STRUCTURE

Once the position of the cab has been fixed a similar study to that described above can be made for the design of the cab structure. Using an electric light bulb here will give a preliminary idea on the directions in which obstructions to vision by girders are to be avoided. More detailed information will be obtained by running a thread from the place where the man's head will be to the various points where he has to look. This makes it easy to measure the angles of his sight lines and the cab structure can be designed on this basis.

When an improvement is made in one aspect of the control situation this often makes another aspect worse unless the situation is considered as a whole. For example, if the driver is given a seat after being used to standing, his ability to lean out is restricted and action is needed to counteract this. Enclosing the cab also makes vision more difficult. The unpleasant physical conditions in many parts of a steelworks often make it desirable that the driver should be enclosed, but militating against this is the fact that enclosure both reduces visibility and increases the psychological feeling of isolation of the driver.

To protect the driver from flying scale and at the same time to allow him to see properly he should be surrounded by fully toughened plate glass. Plastic sheets should be avoided because they are easily scratched, do not stand up to heat and strain, and are liable to optical flaws and defects. Curved glass should not be used because, owing to refraction and

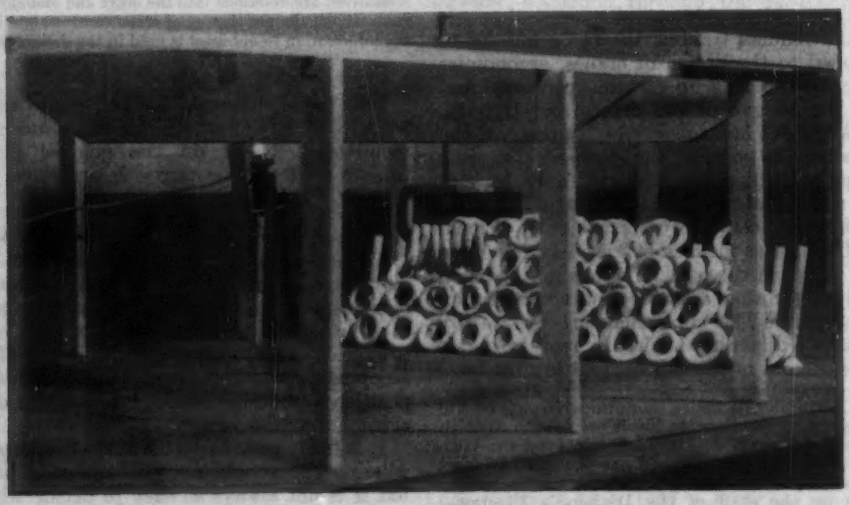

Fig. 2—Model of shop and crane

critical angle effects, distortion is considerably increased and it is difficult to see the operator from the outside. Complex curves should be specially avoided. It is desirable to fit cranes which work in the open air with windscreen wipers over the panes that are used most, but this may raise a difficult maintenance problem.

The window panes should be as large as possible and should all be accessible for easy cleaning. If the cab is not air-conditioned, it should be possible to clean the outside of the glazing from inside the cab. If the cab is air-conditioned, the windows should not open and a platform or a cradle should be fitted so that the windows can be easily cleaned without the cleaners having to climb up precarious structures from the shop floor.

In most cranes the seat should be placed to the side of the cab nearer the hook so that the operator can see through a side window without excessive leaning to one side. The bottom glass at the front and on that side should slope into the base of the driver's seat so that he can easily see down to the shop floor below. Any grilles which are necessary should be fitted outside the sloping glass so that it can be kept clean easily. The cab floor should be kept smooth and clear of cables and other obstructions to prevent the accumulation of dirt and to encourage cleaning. If dirt is allowed to accumulate here, it can easily get on to the glass. Figure 3 shows a model of a cab installed in a works which is based on these recommendations.

## PHYSICAL CONDITION OF WORK

Excessive working temperatures are inherent in the iron and steelmaking process, and this is the physical condition to which most consideration has to be given. In many cranes in the steel industry, such as soaking-pit cranes, ladle cranes, and cranes working near cooling banks or handling hot-finished products, the temperature can be such as to cause the crane drivers considerable distress after long periods in the cab. Exposure to heat leads to an early onset of fatigue and an increased risk of accidents. Heat can be of three kinds—convected, conducted, and radiant—and the first step in protecting the crane driver from excessive heat is to find out in what form the heat is arriving at the cab. The main problem with ladle cranes, soaking-pit cranes, etc. is from radiant heat directly impinging on the cab. One way to prevent this reaching the operator is to cover all opaque parts of the cab exposed to radiation, both inside and out, with a heat-reflecting material such as aluminium sheet. This may, however, be difficult to keep clean or need replacing frequently. Any outside surfaces of the cab not exposed to direct radiation should be 'black,' i.e. a good radiator to allow heat to radiate away from the cab on that side. The glazing of the cab can be of ordinary fully toughened plate glass, but extra panels of heat-absorbing glass should be placed outside these between the driver and the source of the heat. Ventilation would be necessary between the two panels of glass to cool the heat-absorbing glass and prevent the heat being conducted into the cab. Full provision should be made for cleaning all glass surfaces.

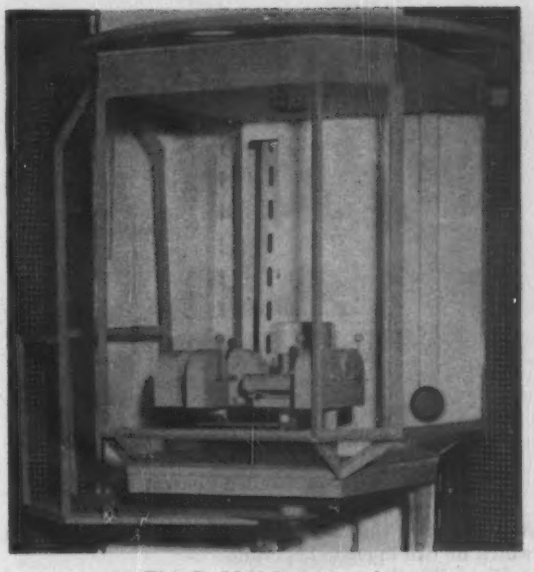

Fig. 3—Model crane cab

The interior of the cab should also be of polished (i.e. heat-reflecting) material because otherwise the cab structure would absorb heat coming through the windows and radiate continually, whereas with heat-reflecting material it will only reflect the heat whilst heat rays are falling on it.

It is advisable also to insulate the inside of the cab and especially the floor with some form of fireproof insulating material to prevent any heat which is absorbed by the exterior of the cab being conducted to the interior.

The air inside the cab will absorb any heat transmitted through the glass or reflected off the interior walls, so some way of circulating and extracting this air is necessary. In very hot cranes or cranes in fumes or dusty shops it may be found necessary also to install a full air-conditioning system which will provide a supply of filtered and cooled air.

On cranes handling hot-finished products and working over cooling banks or stockyards, a large amount of convected heat reaches the driver. Very little appears to have been done to protect drivers working on this type of crane. Air conditioning units would undoubtedly reduce the amount or heat reaching the driver, but very few have been fitted to this type of crane. The main reason is probably that most cranes on this kind of duty are of a light type and the addition of an air-conditioning unit of the type in current use would necessitate their being much heavier. Further work is needed into the development of a small refrigeration unit suitable for use on light cranes. It is possible that improvements could be made in working conditions in this type of shop by a general improvement in the ventilation of the whole building.

## SEATING

In most steelworks cranes the driver has to spend the major proportion of his working shift in his cab operating his controls. If fatigue is to be minimized

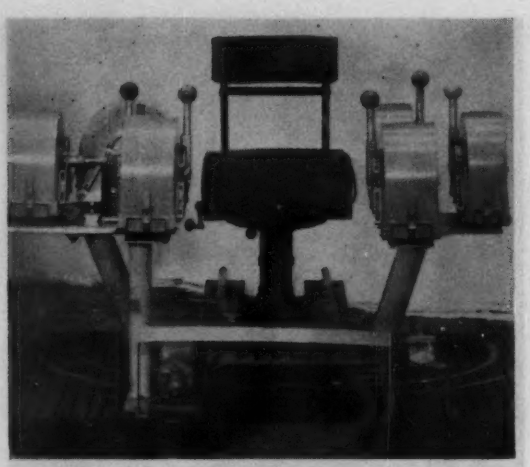

Fig. 4—A recommended control layout

it is essential that he be provided with a seat from which he can operate his crane.

If possible the controls in the cab should be arranged so that the operator can control them from either a sitting or a standing position so that he can get the benefits of the maximum change of position. This means that either a high seat with its own foot-rest should be fitted for seated operation with the controls placed at the correct height for standing operation, or alternatively the controls and seat should be placed for seated operation with the seat arranged to slide back and reveal a well in the floor in which the operator can stand when he wants to operate the crane from a standing position.

Where foot controls are necessary it is difficult to design a foot pedal which can be properly operated from a standing position, let alone one that can be operated both seated or standing, and so in these cases it is usually desirable always to operate the crane from a seated position.

Darcus, of the Medical Research Council, has carried out several studies on seating and has shown that it is essential that a seat should fulfill several conditions.[2] The main one is that it should correctly fit 90% of the people who will have to use it and accommodate the rest. Another is that the driver should be able to change his position frequently to avoid undue fatigue. It is possible to allow this by designing the seat so that the driver can either sit upright or slumped and so that he can cross his legs at will.

The seat should be fairly firm but soft enough to absorb vibrations due to rough rail tracks. The seat must also stabilize the driver during running and sudden decelerations, so that it must be firmly fixed to the floor. It should lock in the working position but should be able to slide back for easy access or escape in an emergency.

The bucket-shaped seat which is still used in many works is not suitable because, owing to its curved back, the driver cannot easily change his position. Another bad type of seat is the type with a pummel which is often used in excavators. This does not usually support the back and, because of the shaped seat, does not allow the anatomically correct weight distribution.

B.I.S.R.A. has given consideration to the design of seating in steelworks and, in conjunction with Darcus and two manufacturers, has developed two seats which are commercially available. The dimensions on which the seats are based were taken on a large number of servicemen during the war and the seats are made to adjust backwards and forwards and up and down so as to fit 90% of the male population. They have swivelling back rests which support the small of the back but allow the driver to sit upright or to slump. With this type of support for the back it is also possible to exert larger forces with the feet to apply foot brakes etc. An example of this type of seat is shown in Figs. 4 and 6.

In many of the cranes in use in the steel industry, such as ingot-stripping cranes and soaking-pit chargers, and in grabbing and dockside cranes in all industries, a large amount of time is spent looking straight down in front of the cab. In these cases the driver can get very little support for his back and further work is needed to find an alternative type of support or seat.

## CHOICE OF CONTROLS

Many electrical master controllers in use are still too large and many still have the awkward semi-circular movement of the controllers illustrated in Fig. 1. Controllers of the type shown in Fig. 4, which are much smaller and have more of a straight-line motion, are much to be preferred.

If a controller handle moves in a straight line or nearly so, the controller can be positioned so that its movement is realistic, i.e. the motion controlled moves in the same direction as the hand controlling it.

If the controllers are made as small as possible, they do not impede visibility to any degree, they allow easy access and escape in danger, and they can more easily be grouped around the operator.

If large controllers have to be used or if space around the operator is very limited, it is possible to position the controllers themselves away from the operator, retaining only the handles around the operator, and to operate the controller remotely by means of a rod, cable, or hydraulic linkage.

This has the added advantage of keeping all the electrical apparatus away from the cab and of allowing the use of different types or makes of controller in one cab but with standard handles. By suitable adjustment of the linkage ratios, a controller which normally requires a semi-circular movement can be remotely operated by means of a straight-line handle.

B.I.S.R.A. has carried out a number of laboratory experiments on the design of electrical master controllers and these are described in the following paper.

Controllers should be kept as small and as simple as possible and works trials have shown that in motions with a large number of notches only two are in use for most of the time. When a crane is being ordered, consideration should be given to how many notches are needed on each motion with a view to obtaining the minimum necessary.

Two considerations have to be borne in mind from the safety point of view when installing controllers in

cranes, and these are bound up with two types of human error which can occur. ' Unintentional ' errors in cranes are mainly the accidental knocking on of controllers by leaning up against them. This can be overcome by the fitting of off-position latches which have to be depressed before the controller handle can be moved out of the off-position.

' Forgetting ' errors in cranes usually occur when a controller is left on. This can best be overcome by ensuring that the off-position is distinct from the other notches and by installing the controllers with all the handles vertical in this position.

The various types of human error are dealt with in more detail below.

## LAYOUT OF CONTROLS

### Psychological Considerations

Most of the early work on the layout of controls originated from research into the causes of pilot errors in aircraft. At Wright Field Research Centre in the U.S.A. it was found that aircraft control errors fell into several categories:

*Adjustment* errors, i.e. failure to operate the controls in the correct sequence
*Confusion of controls*, i.e. mistakenly operating the wrong control
*Reversal* errors, i.e. operating a control in the reverse direction
*Forgetting* errors, i.e. forgetting to operate or turn off a control
*Unintentional* errors, i.e. knocking a control accidentally when moving an adjacent one
*Crowding of controls*, i.e. controls too close together
*Reaching* errors, i.e. inability to reach a control.[3]

Crane and rolling-mill controls are not so complicated as those in aircraft and the consequences of the errors which are likely are not so dangerous but the problems of layout can still be considered under these headings.

The main way to reduce adjustment errors is to study the job and to lay out the controls accordingly. Consideration should be given to the correct choice of controls as discussed in the previous section.

B.I.S.R.A. is carrying out a series of works trials on the amount and order of use of the controllers in cranes in order to obtain more information as a basis on which crane controllers can be laid out.

These trials are designed to find how often the drivers use each controller in a particular crane cab, which pairs of controllers are used together, and in which order the controls are used. The method adopted is to fit an apparatus to each controller which sends pulses through a relay box to a tape perforator all the time the controller handle is being moved. The pulsing apparatus is shown in Fig. 5. Each track on the tape gives a record for one controller so that this method can be used for cranes with up to five controllers. The tapes obtained are analysed on an electronic digital computer.

The trials so far have been carried out on three stripping cranes having long travel, cross travel, hoist, slew, ram, and grip motions, and the preliminary results are now available. In all cases the two travel controllers are often used both simultaneously and sequentially, and this suggests that they should be combined for dual operation or laid out so that both can be operated together, one by each hand. Although the hoists were positioned differently in each of the

**Fig. 5—Apparatus to record when a controller handle is moving**

three cranes, the results for all three trials show that they were used in conjunction with or in sequence with one or other of the travel controllers. The results suggest that a need exists for the hoist to be positioned for convenient simultaneous operation with both travel controllers, and this is best achieved by combining the two travel controllers into a joystick controller and placing the hoist on the opposite side. The grips are also operated largely with the hoist and it is suggested that they would most conveniently be controlled by means of a push-button in the top of the hoist controller.

If a slew controller is fitted, this can be combined with the hoist in a joystick, and the ram controllers positioned for operation by the same hand as the travel controllers. If slewing is not required, the ram controller can be placed opposite the travel controllers.

The possibility of confusion errors can be reduced in several ways. All crane cabs in any particular works, and if possible all works, should be laid out in a standard fashion, so that if a driver is called upon to operate a strange crane he is already familiar with the control layout. Familiarity, however, is often given as a reason for not improving the layout of a crane. In this case a new but non-standard layout, based on some analysis of the job as in the B.I.S.R.A. trials, should be tried out in consultation with experienced drivers and, if successful, all layouts of similar control points should be changed to the new form as soon as circumstances allow.

A crane driver drives his cranes whilst looking at the hook and makes blind positioning reactions to his controllers. The controllers thus should be so arranged that he can operate the correct controller without needing to look, and a standardized spatial arrangement helps this. Differentiation by shape of

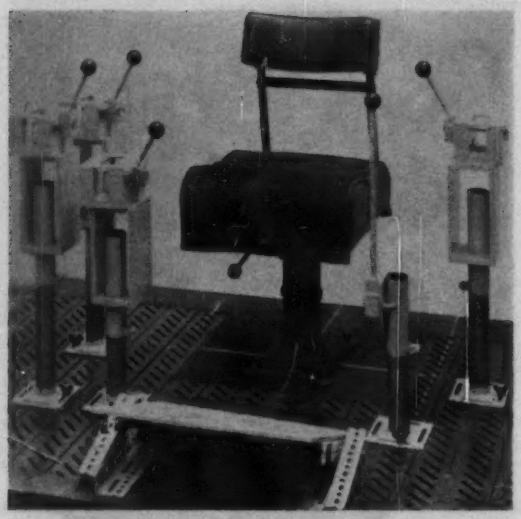

Fig. 6—Mock-up of proposed control point

control handle, as in use in aircraft cockpits, and shape, colour, and size differentiation have been considered by B.I.S.R.A.,[4] but owing to production difficulties and the necessity for keeping stocks of the different shapes it has not been instituted yet in the industry. Where controls are very close together, as in aircraft, this is the best way of differentiating, but in crane cabs where they are further apart it is not so necessary, although it still appears to be attractive since crane drivers often change cranes.

A further assistance to a driver or maintenance engineer when entering a cab is correct labelling of all controllers. Often the only way a stranger to a particular cab can find out the use of any particular controller is to try it out.

Reversal errors can be avoided by having all controller handles move in the expected direction.

Forgetting and unintentional errors are covered in the preceding section, and crowding of controls and reaching errors are covered in the following section.

In giving the results of the B.I.S.R.A. works trials mention was made of the possibility of combining two controllers for joystick operation by one hand. This is of great value in multi-motion cranes because it means that the driver does not have to move his hand from one handle to another quite so often. With some designs, however, it is possible inadvertently to get into the first notch of the motion at right-angles to the one being controlled. B.I.S.R.A. is hoping in the future to carry out research into the design of such dual control mechanisms.

#### Anthropometric Considerations

Research in motion study has shown that hand movements should be as smooth as possible and in general be restricted to the smallest number of muscles, i.e. small controls should only need the fingers to operate them. Barnes has worked out the distances around the operator within which hand movements should be contained.[5]

This work was done, however, with reference to assembly tasks, and it does not necessarily mean that the results are applicable directly to the layout of controls. They are true for the occasional use of a control, but, where continuous operation is necessary as in cranes, a higher class of movement will be desirable. Thus the wrist and forearm should be used rather than the fingers alone, and there is no reason why a crane driver should not have to move his trunk a little to reach a control. He should not, however, have to reach round to operate two controls together on one side whilst still looking ahead nor should he need to operate simultaneously two controls which require him to move his trunk in opposite directions.

When a control point such as a crane cab is being designed, care should be taken that all the controls are placed so that they are within reach of all sizes of people who are likely to be working there. It is possible to get a rough idea of where the controls should go on the drawing board by using two jointed anatomical templates to represent small and large sized men. It is not good enough to base layouts only on average-sized men because then the equipment is only suitable for approximately 50% of the total male population. It is necessary to consider the whole range of individual variations and to aim to suit at least 90%. The use of templates can only give a rough idea, however, because it does not take account of variations in individual limb sizes and movements.

The best way of ensuring that the controls are correctly placed is to build a full-size adjustable 'mock-up' of the control point in question and get each of the future operators to adjust the equipment so that all the controls are conveniently placed. Studies of this sort not only give the best positions of the controls but have a psychological advantage in that the operators know they are being consulted from the beginning and thus take a useful interest in the new plant and its future operation.

B.I.S.R.A. has carried out a study of this kind on the layout of a rolling-mill pulpit and is proposing to carry out further similar tests in the near future on another mill pulpit and on a crane cab.

An illustration of the apparatus used for this type of study is shown in Fig. 6. It consists of full-size wooden outline models of the type of controllers which are proposed for the control point, an anthropometric seat, an adjustable foot rest, and a wooden baseboard covered with slotted metal sheet. The seat is fixed to the baseboard and the controller models are made so that their heights from the ground and their positions on the baseboard can be varied. Wing nuts ensure that once placed the controllers can be fixed in position.

The procedure which is followed on the trials is as follows. The apparatus is taken to the works and set up in a convenient room, and operators are brought to it for short periods during their normal shift. As many operators as possible who will be likely to work the control point are tried out in the apparatus. Each operator sits in the seat, which is then adjusted according to his size so that he is correctly seated. The controllers are then roughly placed around him so that they are in the approximate

position relative to each other as determined by other studies. Each operator is then asked to position the controllers so that they are most conveniently situated to suit his own preferences. At the same time his comments are obtained on the control-point layout in general.

Measurements are taken of the height each man sets the controls and the positions on the baseboard relative to two co-ordinates. If possible note is taken not only of the optimum position for each man but also of the range within which some movement can be made before the controller is placed out of reach. When all the operators have been tried, a composite table is made up showing all the positionings. An assessment should be made of this so that the controls can be placed to suit the maximum number of operators' preferences. Finally the mock-up is set up according to this assessment and all the operators are tried out to check the results.

Several manufacturers now supply complete control units including a seat and a number of built-in controllers. It is important to consider the seat-controller unit as an integrated whole, but unfortunately these ready-made units do not often come up to the standard as far as ergonomics is concerned.

The main drawback is the type of seat fitted. These are very rarely of the correct anatomical shape and do not support the back in the correct working position. Sometimes horizontal adjustment is fitted but there is not often any in the vertical plane.

Consideration is given to the aesthetic design of the unit but not enough thought is given to the positioning of the controller handles. These are sometimes placed out of reach or so that their handles move at right-angles to the expected direction. With these built-in units it is also more difficult to re-position the controllers, once their position has been decided. Nevertheless, the tendency to design control points with the aim of integrating the operator and his controls is welcomed and further improvements will no doubt be made shortly.

## AIDS TO DRIVING

Under certain conditions it might be worth considering making automatic any part of the operation which is repetitive. For instance, with a grab crane which always discharges into a fixed bunker it would be possible to position the grab automatically for this part of the cycle.[6] This might allow greater freedom in positioning the cab of the crane because the driver does not then need such a good view of the discharging point. It would be a mistake, however, to place the cab so that he could not see the discharging grab at all, as he should always be able to monitor the operation to ensure complete safety.

It is not always necessary to go to such lengths as to install complete automatic control to help the driver. The use of limit switches to prevent the crane crab or hook passing certain limits allows the driver to concentrate on the other motions. This is especially useful in the case of hoist limit switches on fast-moving cranes with limited head room. In this case the driver can let the hoist look after itself whilst he concentrates on controlling the travelling motions. If only one limit switch is fitted, this should regularly be given a careful inspection to maintain it in good working order. On new cranes two limit switches should be fitted.

Another aid to drivers of cranes which regularly have to pick up or deposit loads in one place, as for instance when weighing loads or picking up off cooling beds, is to place marks on the cross-travel girders so that they can line the crab up with these before reaching the position and so save time.

## COMMUNICATION WITH THE CRANE DRIVER

It is essential that the crane driver should know what he has to do with each load, what is going on in the shop in which he is situated, and often, what is happening in other parts of the works.

The traditional way of communicating with the driver is by hand or auditory signals such as shouting or whistling. These must be standardized, unambiguous, and easily distinguished from other signals or noises.

With the enclosing of cabs and with the fitting of air-conditioning plant, however, the driver becomes more isolated from the rest of the shop and cannot hear what is going on. Other measures have to be taken to keep in contact with him. Some form of radio or carrier-frequency telecommunication system should be fitted for giving information to the driver, although hand signals are probably a suitable way for passing information regarding each individual lift.

A method of communication which is often used for telling the driver the state of other parts of the plant is the use of indicator lights. These are often used, for instance, to show whether a mill is in operation or whether certain conveyor belts are running.

When a crane is being installed careful consideration should be given as to how necessary these lights are. If it is decided that they are really necessary, a maintenance programme should be instituted because all too often indicator lights are seen in use in which the bulbs have been broken for some time and of which no notice is ever taken. It might be possible to have a central display which is visible to several cranes and which can be kept in working order. For greater reliability the bulbs should be placed in parallel so that if one goes wrong the other still works.

## Acknowledgments

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## References

1. L. N. BRAMLEY: *J.I.S.I.*, 1953, vol. 173, pp. 53–68.
2. H. D. DARCUS: "Seating in relation to anatomical and physiological principles," Royal Naval Personnel Research Committee, RNP46/326, 1946.
3. A. CHAPANIS, W. R. GARNER, and C. T. MORGAN: "Applied Experimental Psychology": 1949, New York, John Wiley and Sons Inc.
4. L. N. BRAMLEY: Unpublished B.I.S.R.A. Report No. PE/B/64/51.
5. R. M. BARNES: "Work Methods Manual": 1944, New York, John Wiley and Sons Inc.
6. L. N. BRAMLEY: Unpublished B.I.S.R.A. Report No. PE/R/22/58.

# Ergonomic Investigations into the Design of Master Controllers

*By A. Box and R. G. Sell*

SYNOPSIS

The paper describes a series of laboratory experiments and works trials in which a detailed investigation of the ergonomic aspects of the design of steelworks hand- and foot-operated master controllers was carried out. In the laboratory experiments a group of subjects operated test controllers under various conditions, and their times to perform a standard task were recorded and used as a criterion of operating efficiency.

The main conclusions drawn were that a pivotal-type foot controller should be provided with two or three speed-steps in preference to four speed-steps and should have an operating torque in the range 30–60 lb-in.; the pivot should be positioned some 5 in. in front of the back of the pedal and not more than 1 in. above nor more than 2 in. below it.

A hand controller should be provided with four speed-steps rather than with three or six and have a handle 9–12 in. long; the controller should be provided with a location mechanism giving a light and smooth feel and should have an extra location to the off-position. Provision of a mechanical safety latch for the off-position did not significantly affect performance.

The series of works trials described was concerned with determining the relative use made of the notches of the long-travel controllers during the normal operation of four stripper cranes. Results indicated that some reduction in the number of notches and thus of the size of the controller was possible without impairing the efficiency of the crane.

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THIS PAPER describes a series of laboratory experiments and works trials carried out by the Ergonomics Research Section at B.I.S.R.A. into the ergonomic aspects of the design of both hand- and foot-operated master controllers. The series of experiments described is still at an interim stage and more work remains to be done, for example, on the design of foot controllers.

Ergonomics research in general deals with the design of plant and equipment and the establishment of environmental working conditions, taking into account the capabilities and limitations of the human operator. The aim of this approach is to determine the conditions in which human beings may be expected to work at their maximum efficiency and with a minimum risk of accidents and delay. A fuller description of the general aims and methods of ergonomic research and the benefits of its application to industry is given in the previous paper. In the experiments described in this paper, the effects of certain design variables of both hand and foot controllers upon the operating characteristics of the controller were studied in detail, and the main object was to determine the optimum combination of these design variables for the most efficient performance of the work.

The interest shown by B.I.S.R.A. in the design of hand-operated controllers arose some ten years ago out of a survey of steelworks cranes made in connection with the preparation of a specification for steelworks electric overhead travelling cranes.[1] From the operating viewpoint, existing hand controllers were criticized because of their large size and bulkiness, which impeded the line of vision of the driver and made ready access for maintenance difficult, and because the handles moved in wide arcs, usually in a horizontal plane, which made it impossible to obtain a realistic control motion and to combine two controllers into a single joystick controller. Both these aspects of the design of the then existing controllers made it difficult to obtain a compact layout of the controls arranged for easy and convenient operation.

Recommendations made on these points at that time were based mainly on such literature as then existed.[2] These recommendations required the development of a hand controller which was small and compact and the handle of which moved in a restricted arc in the vertical plane almost corresponding to a straight line so as to overcome the faults of existing controllers. A controller, the B.I.S.R.A./S.W. master controller, fulfilling nearly all these requirements but still somewhat larger than desired, was developed and is now available commercially and in use in several steelworks. At the time of writing a really small hand controller is under development and is undergoing works trials. The work required to develop these controllers, after the initial operating requirements were specified, was of a mechanical and electrical engineering nature rather than ergonomic and will not be described here. This does, however, illustrate a basic point about ergonomic research: once the ergonomic conditions for the design of a piece of plant or equipment have been established, it often requires a great amount of engineering ingenuity and development to satisfy them. Ergonomics as it were adds a new dimension to work design and the final outcome in practice is usually a compromise between different and often conflicting design considerations. The point is made, however, that the results of ergonomic research are of fundamental importance and that time will be saved and the final outcome will be more satisfactory if a man–machine system is considered as a whole from the start.

The B.I.S.R.A. hand-controller experiments described in this paper were all carried out on the 'straight-line' type of master controller developed out of the original work mentioned above. The experiments on foot controllers were all on a pivotal, as

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The authors are on the staff of the Division's Electrical Engineering Section.

distinct from a push, type of controller. Foot controllers are far less frequently used in steelworks than are hand controllers, and the work on them was carried out because it was thought that the provision of a well designed foot controller, with the consequent spread of work-load over four limbs instead of just two, would do something towards improving the operating efficiency of steelworks control points. Both the hand and foot controllers studied were of the type which work in a series of discrete speed-steps.

The experiments are described under five main headings:

(1) Basic apparatus and procedure for the laboratory experiments
(2) Foot-controller experiments
(3) Hand-controller experiments
(4) Works trials
(5) Conclusions.

A fuller description of the experiments and statistical analyses involved are given in the B.I.S.R.A. reports listed in the references.

## BASIC APPARATUS AND PROCEDURE FOR THE LABORATORY EXPERIMENTS

The basic apparatus and procedure was similar for all the laboratory experiments on hand and foot controllers described in this paper. The apparatus consisted of a hand or a foot controller controlling the speed and direction of a pointer moving up and down a vertically mounted scale and connected through a set of relays to a paper-tape perforator. The perforator and the scale are illustrated in Fig. 1. The scale was also provided with a second pointer which could be placed in any position by hand.

The experimental controller in each case was either specially designed or was a modified B.I.S.R.A./S.W. master controller. For each experiment the controller was designed or modified so that certain of the physical aspects of its design which were to be studied could be systematically varied through the course of the experiment. A fuller description of these variables is given in the description of the experiments concerned. In each experiment the controller was conveniently placed alongside a B.I.S.R.A. anthropometric seat and within view of the scale and pointers.

The scale consisted of a hardboard screen 10 ft long and 5½ in. wide mounted vertically in front of the seat, 10½ ft from it for the earlier experiments and 17 ft from it for later experiments. In the first experiments the scale was painted white and the pointers either black or silver, but in the last experiment the scale was black and the pointers white. This last colour scheme was adopted to minimize glare and to obviate troublesome shadows behind the pointers. The pointer controlled by the operator was carried on a wire passing round a grooved wheel on the shaft of a fractional h.p. electric motor at the bottom of the scale and round a pulley at the top of the scale. The speed and direction of the pointer was controlled in discrete speed-steps. The number and speeds of these steps varied from experiment to experiment. The second pointer was also carried on a wire passing round two pulleys and was on the opposite side of the scale to the first pointer.

The perforator was connected to the controller so that each of the speed-steps was associated with a particular coding of tracks on the punched tape. The circuit was such that the perforator began to record as soon as the controller was moved from the off-position and continued to record as long as the controller was in use. Use made of the off position intermediary between two speed-steps, e.g. when reversing direction during inching movements, appeared as a length of blank tape. By this means a punched-tape

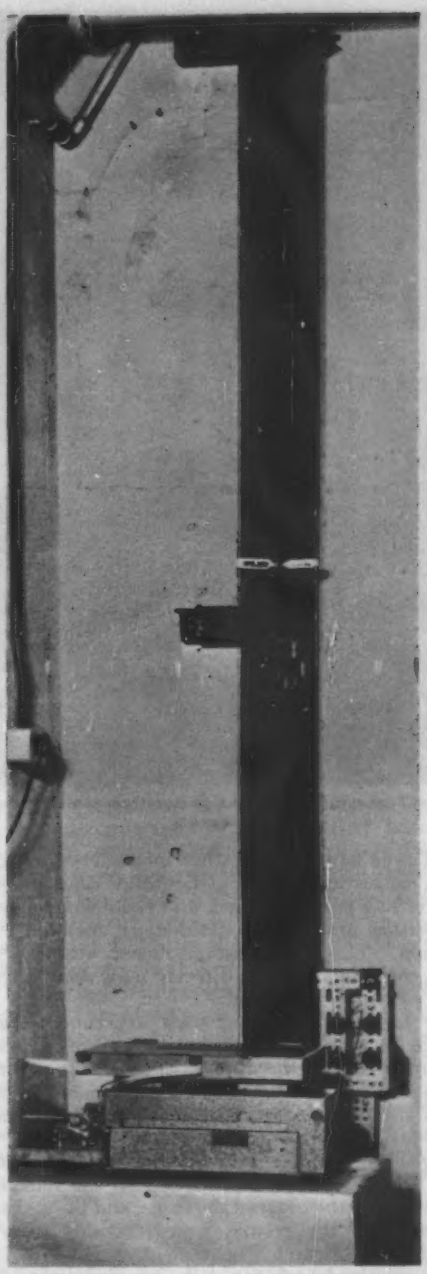

Fig. 1—Scale and perforator used in laboratory experiments

**Fig. 2—Test controller used in position of pivot experiments**

record was obtained of the controller movements made, consisting both of the total time taken to perform any particular task and the use made of the off position and of the speed-steps, including their direction. This punched-tape record was in a form which could be analysed directly by a relay analyser or an electronic computer.

The basic procedure in each experiment was to arrange for a group of subjects to perform a series of standard tasks on the apparatus using the controller set up in the various conditions corresponding to the design variables under experiment. The experiments were spread over several days and the tasks were arranged so that each subject used the controller set up in all the conditions. Advice on the number of subjects used, the order of the tasks, and the statistical treatment of the results were obtained from the Operational Research Department at B.I.S.R.A.

The standard task for each experiment consisted of aligning the two pointers on the scale four times by manipulation of the controller. The starting points for each alignment were fixed so that two runs were made up and down the length of the scale followed by two runs up and down half the length of the scale. After each run the second pointer was repositioned on the scale by the experimenter by hand. A permissible tolerance of alignment of $\pm \frac{1}{8}$ in. was indicated by two wires protruding beyond the tip of the second pointer. The subjects were instructed to perform the task as quickly as possible, but the need for accuracy was stressed. The accuracy of each alignment was checked visually by the experimenter.

The perforator recorded the total time taken by each subject to complete the standard task and also the use made of the speed-steps. The time obtained in this way was taken as a criterion of the operating efficiency of the controller under the particular condition being studied. Appropriate statistical analysis of the sets of times obtained then provided a measure of both the interactive and the individual effects of the different design variables. The statistical design and analysis of the experiments included safeguards against the effect of learning and other factors masking the influence on performance of the different conditions of the controller.

## FOOT-CONTROLLER EXPERIMENTS

Two experiments on foot controllers have been carried out: in the first the position of the pivot relative to the ankle was studied,[3] and in the second three variables were studied.[4] These were the number of speed steps available, the angle between the two extreme positions, and the operating torque. The first of these experiments was preceded by a preliminary investigation[5] designed to reduce the possible number of pivot positions to an amount conveniently manageable in a single experiment and to ascertain the area in which the optimum position might be expected to lie. This preliminary investigation will be described first.

### Position of Pivot: Preliminary Investigation

The apparatus for this investigation consisted of a B.I.S.R.A./S.W. master controller modified for foot operation (Fig. 2). The handle was removed and a Duralumin arm, 14 in. long, drilled and tapped at 1-in. intervals, was fitted. The arm had a moveable support attached to it and on to this was attached a foot pedal which could itself be moved backwards and forwards in 1-in. steps for a total of 8 in. The pedal was provided with a heel rest and was studded to prevent the foot slipping. The position of the ankle relative to the pedal was taken as being 3 in. from the back of the pedal and 3 in. above it. Thus by adjustment of the pedal on the support and on the Duralumin arm a total of 117 different positions of the ankle relative to the pivot were obtained. Two pointers moving over a graduated scale were fixed to the spindle of the controller on the opposite side to the pedal and were used to measure the angular deflection of the forwards and backwards movement of the controller.

For purposes of the preliminary investigation thirteen out of the possible 117 positions of the pedal were selected. These positions clustered around the conventional pivot position for foot pedals (i.e. a point 3–4 in. immediately below the ankle) but extreme positions were also represented. Twelve male subjects were used, each of whom operated the pedal at every one of the thirteen selected positions in random order and at one sitting lasting 45 min. The pedal was maintained in a convenient operating position relative to the seat by altering the position of the controller and by adjusting the seat. This operating position was one in which the angle between

the upper and lower leg at the knee was approximately 110° and the sole of the foot at 90° to the lower leg with the controller in the off-position.

The subjects were instructed to move the pedal backwards and forwards through as large an angle as was comfortable, and this angle was recorded. The subjects were also given a verbal questionnaire and asked to rate each setting on a five-point scale for five operating characteristics of the pedal. These characteristics were the position of the pedal in respect to height, difficulty in moving the pedal forward, difficulty in moving the pedal backwards, comfort of movement, and effort exerted.

From these criteria of comfort of operation and range of movement by which the different positions were assessed, the following conclusions were drawn:

(1) The pivot should not be more than 6 in. below the ankle and not more than 1 in. above the ankle; it should not be behind the ankle nor more than 4 in. in front of it.

(2) The mean arc of comfortable movement was: forward — 31° with a standard deviation of 6½°; backward — 25° with a standard deviation of 8°. Results of the questionnaire indicated that a light feel was required for this type of foot pedal and that the initial operating position adopted was correct.

**Position of Pivot: Main Experiment**

The same controller was used in the main experiment as for the preliminary investigation, except that the pointers were removed and the lower 4 in. was cut off the Duralumin arm. The controller was connected to the pointer and perforator as described above. A toe-down movement of the pedal caused the pointer to move down the scale and a heel-down movement caused it to move up the scale. The controller worked in a series of discrete steps and was provided with five speed-steps in each direction from the off position. The speeds were as follows:

| Steps | Speed of Pointer, ft/s |
|---|---|
| 1 | 0·6 |
| 2 | 1·4 |
| 3 | 2·1 |
| 4 | 2·9 |
| 5 | 3·2 |

The range of movement of the pedal was 32° forward and 32° backward. This conformed approximately with the results of the preliminary investigation.

Fifteen positions of the pivot relative to the ankle were studied and these were spaced rectangularly at 2-in. intervals within the rectangle defined as the optimum area from the results of the preliminary investigation. Seven male subjects were used for the experiment, none of whom was a member of the original twelve. Before each session, the controller and seat were adjusted for each subject as for the preliminary investigation.

Each subject performed the standard task with three pedal positions per day, and the order in which the positions were taken was randomized separately for each subject. The experiment was spread over 15 days so that each subject operated the pedal in every position three times. At the end of each five-day period, when each subject had completed all the positions, the order of presentation was again randomized. At the end of the standard task for each position the subjects were again given a verbal questionnaire similar to that used for the preliminary investigation. Before recording began, each subject was given two trial periods of 20 min each on two successive days. During the experiment it was found that one of the positions was almost impossible to operate for nearly all the subjects, and this position was consequently omitted.

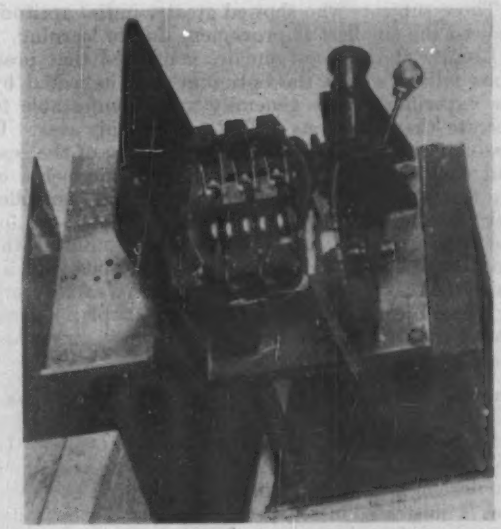

Fig. 3—Test controller used in foot-controller experiment

For each position of the pivot the times taken by each subject to perform the standard task were aggregated. Time spent in the off-position was eliminated from these aggregates, which thus represented the time during which the pointer was actually moving. Analysis was also made of the use made of the speed-steps. From examination of these figures the following conclusions were drawn:

(1) The optimum position of the pivot in a pivotal-type foot-operated controller lies not less than 2 in. nor more than 5 in. below the ankle (ankle position as defined above). It should be 2 in. in front of the ankle. Translating this into terms of the position of the pivot relative to the pedal and assuming the controller is operated with the heel against the back of the pedal, the pivot should not be more than 1 in. above the pedal nor more than 2 in. below it. It should be 5 in. in front of the back of the pedal.

(2) Subjects varied in their ability to operate the foot controller and the differences in performance between subjects was greater than the differences due to changes in the position of the pivot. This means that for optimum efficiency, attention must be paid not only to the pivot position but also to operator selection.

(3) Subjects who used the fewest speed-steps tended to perform the task most rapidly.

(4) Learning of such a motor skill as operating a foot pedal takes a considerable time and in this case was still going on at the end of three weeks.

Those subjects who showed greater initial aptitude showed the smallest improvement due to learning.

Results of the questionnaire confirmed that positions falling within the optimum area indicated by the experiment were generally more comfortable to operate than positions falling outside this area. It was confirmed that the initial positioning of the seat and controller were satisfactory. Measurements of the turning moment required to move the controller were 36 lb-in. for the off position and 24 lb-in. for the speed-steps. This torque was measured at the front end of the pedal. Results of the questionnaire indicated that these forces were considered satisfactory by the subjects. The most common complaint made was of the lack of a positive location indicating when the controller was in the off-position.

### Angular Movement, Number of Speed-steps, and Operating Torque

In the second experiment on foot controllers, the controller was specially designed to facilitate changing the design variables which were studied. The apparatus is illustrated in Fig. 3. The foot pedal was similar to that used in the pivot investigation and the pivot was positioned 5 in. from the back of the pedal and immediately below it. The spindle of the controller carried a series of cams actuating a set of microswitches and control of the pointer was exercised by this means.

Each of the three design variables studied was tested at three levels as follows:

(1) Number of speeds available: two, three, and four on each side of the off-position
(2) Angle between the two extreme positions: 30°, 40°, and 50°
(3) Operating torques: 30, 60, and 72 lb-in.

These variables were obtained by means of three interchangeable location plates attached singly to the spindle of the controller. Each of these plates had three groups of notches equally disposed around its periphery. The notches were 0·262 in. wide and had an included angle of 90°. The first plate carried five notches in each group, the second plate seven, and the third plate nine. These corresponded to two, three, and four speed-steps respectively in each direction plus an off-position notch in each case. The three groups of notches in each plate subtended an angle between the extreme notches of each group of 30°, 40°, and 50° respectively. With the plate in position on the spindle of the controller, any one of the group of notches could be made to pass over a spring-loaded roller of $\frac{1}{2}$ in. dia. Thus by interchanging the plates and by changing the position of the plate on the spindle the three levels of the first two variables could be effected. The operating torque was varied by varying the pressure of the spring on the roller. The force was measured in a straight line passing through the front of the pedal and perpendicular to it. Combination of these variables gave a total of 27 settings studied. An off-position latch was also fitted which required to be disengaged with a downward force of 10 lb before the controller could be moved from the off-position. Once the pedal was moved from the off-position this force could be relaxed.

The speeds of the pointer were as follows:

| Steps | Speeds, ft/s 2 Speed-steps | 3 Speed-steps | 4 Speed-steps |
|---|---|---|---|
| 1 | 0·4 | 0·4 | 0·4 |
| 2 | 1·85 | 0·83 | 0·83 |
| 3 | ... | 1·85 | 1·25 |
| 4 | ... | ... | 1·85 |

Movement of the pointer relative to movement of the pedal was in the same direction as for the pivot experiment.

Six subjects were employed in the experiment, and they each attended the laboratory for a total of 18 sessions in two series with a two-week interval. During each session the subject performed the standard task six times in succession with each of three different settings. During the nine sessions of the first series, each subject performed the task with all of the 27 settings arranged in random order, and in the second series repeated all the settings in the reverse order. The order in which the settings were taken was reversed between alternative subjects.

Each subject was given a preliminary training period to avoid masking the effects of the design variables upon the operating efficiency of the controller by any initial learning effects. This training period was identical for each subject and spread over six sessions, during which each subject performed six times with each of three different settings of the controller. The settings were chosen so as to give each subject experience of the three levels of all the variables.

The data obtained from the experiment consisted of the times each subject took to perform each block of runs with the different settings of the controller. These times were analysed separately for each subject and were also subjected to an analysis of variance. The effect of each of the separate variables was also analysed from the overall data from the six subjects. The two series into which the sessions were divided were analysed separately in the analysis of variance because a preliminary inspection of the data indicated that a learning effect was still present which divided the two series. Analysis of the individual results indicated that in general the conclusions reached were consistent between subjects in trend but not in degree.

From the analysis of the results the following conclusions were drawn:

(1) The two most important variables considered were the number of speed-steps available and the operating torque.

(2) The use of two and three speed-steps resulted in very similar performances in the tests, but both were significantly superior to performance using four speed-steps.

(3) The use of 72 lb-in. operating torque was significantly inferior in performance to the use of 30 and 60 lb-in. operating torques, which produced similar results.

(4) Changing the angular separation between the two extreme speed-steps had little apparent effect. There was a very slight indication that 40° and 50° were preferable to 30°.

(5) Generally, the effects of operating pressure and the number of available speed-steps were independent and it appears that, after rejecting the 72 lb-in. operating torques, four speed-steps, and the 30° angular separation as being inferior, it makes

little difference to operating efficiency which other combination of the variables is used.

### Further Developments

These two experiments conclude the work so far carried out by B.I.S.R.A. on the design of foot controllers. Further work needs to be done on the pivot-type controller, particularly on the design of the off-position and location mechanisms. Other types of foot controller might also be studied and a comparison made between the optimum designs of each type and their suitability for various jobs.

## HAND-CONTROLLER EXPERIMENTS

Two experiments have been carried out on the design of hand controllers, in each of which three design variables were studied. The first experiment investigated the number of speed-steps, the arc of movement of the handle, and the length of the handle.[6] The second experiment investigated the feel of the controller and the effect of providing a mechanical latch and also a more positive location for the off position.[7]

### Number of Speed-steps, Arc of Movement, and Length of Handle

The three variables for this experiment were each tested at three levels, as follows:

(1) Speed-steps: three, four, and six on either side of the off-position
(2) Arc of movement of the handle: 20°, 35°, and 50° in each direction
(3) Handle length: 9 in., 12 in., and 15 in.

Combination of these levels of the three variables gave a total of 27 settings studied.

The controller used was a modified B.I.S.R.A./S.W. master controller (Fig. 4). The handle was removed and a Duralumin crank 9½ in. long was fitted to the controller spindle and extended below it. This crank was provided with a pin at its lower end which fitted loosely into a slot in a pivoted vertical lever with a handle at its upper end. The pivot of this lever was housed in a box, the height of which was adjustable independently of the height of the controller. The handle was telescopic and adjustable for the three different lengths required. Adjustment of the height of the pivot allowed the handle knob to be always in the same position relative to the seat. A variable-friction device was also incorporated into the pivot to ensure that the force required to move the handle was similar for the varying lengths.

The experiment required that the handle should move through any one of three arcs of different length whilst the controller spindle was moving through any one of three fixed arcs corresponding to the range of movement required for the test controller to achieve its maximum speed in three, four, or six steps. This was accomplished by first placing stops so as to restrict the movement of the crank fitted to the controller spindle to any of the three arcs of movement required. Then, by varying the perpendicular distance between the pivot of the crank (i.e. the controller spindle) and the pivot of the lever and handle, the handle could be made to turn through any required arc to turn the controller spindle through its fixed arc. The distance between the two pivots was adjusted by varying the height of the controller.

**Fig. 4—Test controller used in hand-controller experiment**

Thus by suitable manipulation of the apparatus the 27 settings of the experiment could be obtained whilst the other operating characteristics were kept constant. The speeds of the pointer were as follows:

| | Speeds, ft/s | | |
|---|---|---|---|
| Steps | 3 Speed-steps | 4 Speed-steps | 6 Speed-steps |
| 1 | 0·22 | 0·22 | 0·22 |
| 2 | 1·3 | 0·7 | 0·7 |
| 3 | 2·7 | 1·9 | 1·3 |
| 4 | ... | 2·7 | 1·9 |
| 5 | ... | ... | 2·5 |
| 6 | ... | ... | 2·7 |

Controller and pointer were so connected that moving the handle forward caused the pointer to move downward and moving the handle backward caused it to move upward.

Three subjects took part in the experiment and the experiment was spread over three weeks. For the first two weeks each subject performed the standard task daily with either five or six different settings of the controller, so that in each week each subject performed one standard task with all the 27 settings. For the third week, to differentiate the performance times more clearly, the standard task was performed five times continuously for each setting. The 27 settings were randomized into three blocks of nine and each subject performed the three blocks each week in a different order.

The data from the experiment were subjected to an analysis of variance. The time spent in the off position was omitted from these data, which thus represented the time for each task during which the pointer was actually moving. Since the results for the first two weeks showed a considerable improvement in performance because of learning, only the results for the third week were analysed.

From the analysis of the results the following conclusions were drawn:

(1) Performance in the experiment was significantly better when using four speed-steps than with either three or six steps.

(2) With three or four speed-steps, handle lengths of 9 in. or 12 in. were significantly better than a handle of 15 in. With six speed-steps no significant difference between the three handle lengths occurred.

(3) With six speed-steps an arc of movement of 20° in each direction was significantly worse than either 35° or 50°. This tendency was also present for three and four speed-steps, but the difference was not statistically significant.

### Feel of Hand Controller

The hand-operated master controllers at present available for use in steelworks work in a series of discrete speed-steps, and it is essential for the avoidance of electrical faults that the handle should be accurately located in each step.[2] This is to ensure that the electrical contacts are either fully open or fully closed in each position. The location is usually accomplished by a series of notches, corresponding to the speed-steps, passing over a spring-loaded roller. Such a mechanism gives a characteristic ' feel ' to the controller, and by varying the design of the mechanism different ' levels ' of feel are obtained. The experiment now to be described comprised a study of the effect of different levels of feel obtained from a notch-type location upon the operating efficiency of the controller and represents an attempt to determine the optimum location-mechanism design.

The main experiment was preceded by a small-scale preliminary investigation which will be described first.[8]

### Preliminary Investigation

The preliminary investigation was undertaken to select two settings of the location mechanism giving the levels of feel required for the main experiment. The work was necessitated because the number of design variables of the mechanism which might effect the feel was inconveniently large to be handled in a single experiment and little was known of their relative influences.

The investigation was conducted using a mock-up notch-type location mechanism on which several design variables could be set up and assessed for their effects upon the feel of the controller. The settings were assessed for their feel characteristics subjectively by one investigator. Five design variables were studied in this way:

(1) The diameter of the roller
(2) The compliance of the spring
(3) The included angle of the notch
(4) The radius of the peak between notches
(5) The operating force.

Each of these variables was tested at three levels, giving a total of 243 settings investigated.

From this investigation it was concluded that the diameter of the roller and the angle of the notch were relatively unimportant in regard to their influence upon the feel of the controller, and two settings were selected for the main experiment from the range investigated. These settings are described below.

### Main Experiment

The feel of the controller was studied at three levels. These were:

(1) No feel (i.e. no location mechanism)
(2) A fairly light and smooth feel
(3) A very positive and fairly tight feel.

The light feel was obtained by using a 1-in. dia. roller, a 0·062-in./lb spring, and a 120° × $\frac{5}{16}$ in. radius notch. The positive setting used the same roller and notch angle, and the variation in feel was obtained by using a 0·031-in./lb spring and a $\frac{1}{16}$-in. radius to the peak between the notches. For both settings an operating force of $2\frac{1}{2}$ lb was selected, this being the lightest force studied in the preliminary investigation compatible with adequate location and with little risk of the controller handle being accidentally jerked or knocked out of position.

Two further variables were studied in the experiment. These were:

(1) The provision or not of a mechanical safety latch for the off-position. This consisted of a device whereby the controller knob had to be depressed before the handle could be moved out of the off position
(2) The provision or not of an extra locating mechanism for the off-position.

The extra locating mechanism consisted of a set of notches and a roller locating the off-position only additional to the notches and roller providing the location for the ordinary speed-steps. The setting chosen for this was that used to provide the light feel. Two different arrangements of these extra notches were tested providing two different ' feels ' for the off-position. In the first the edge of the plate carrying the notch continued on either side of the notch level with its peak and thus location was provided only

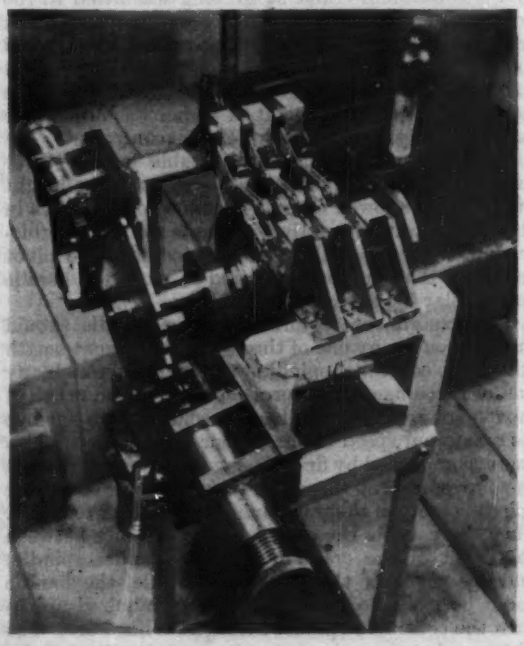

Fig. 5—Test controller used in feel of hand-controller experiment

when the handle was actually in the off-position. In the second the edge of the plate was relieved on either side of the notch, and this arrangement gave in addition an indication that the handle was moving out of the notches immediately adjacent to the off-position.

Combination of these variables gave a total of eighteen settings investigated.

The controller used in the experiment was specially designed and is illustrated in Fig. 5. The pointer was controlled through an arrangement of cams and micro-switches. The controller was provided with four speed-steps in each direction spaced at 9° intervals. The speeds of the pointer were as follows:

| Step | Speed, ft/s |
|---|---|
| 1 | 0·4 |
| 2 | 0·83 |
| 3 | 1·25 |
| 4 | 1·85 |

Movement of the handle forward caused the pointer to move down the scale and movement of the handle backward caused the pointer to move up the scale.

The four sets of notches used in the experiment were all carried on one plate attached to the spindle of the controller, the notches corresponding to the off-position and the speed-steps. The rollers and springs were arranged around the plate so that they could be brought into operation, either singly or in pairs, or not, as required. The required operating force was obtained by adjusting the springs. This force was measured in a straight line perpendicular to the handle and passing through a point immediately under the knob. Each set of notches was calibrated separately and therefore in those settings in which two sets of notches were in operation simultaneously (i.e. those settings in which extra indication was given for the off position) the operating force required to move out of the off position was 5 lb.

Six subjects took part in the experiment, and they each attended the laboratory for two sessions per day for six days spread over two weeks. During each session each subject performed the standard task six times running with each of three different settings of the controller, so that in total each setting was performed twice. The order of presentation was different for all subjects both within sessions and overall. After performing all the eighteen settings in one order, each subject repeated the series in the reverse order.

Before starting the experiment proper, all the subjects were given six training sessions. The settings were arranged during these training sessions so that every subject received an equal amount of training with all of the eighteen settings.

From the results of the experiment the following conclusions were drawn:

(1) Performance with the light and smooth feel was significantly better than performance with either no feel or with the positive feel, which did not significantly differ.

(2) Provision of extra location for the off-position resulted in significantly better performance, though there was no difference between the two types of extra location provided; this effect was present for all conditions of feel, though it was most marked for the condition of no feel and least marked for the positive feel.

(3) Provision or not of the off-position safety latch made no significant difference in performance.

## WORKS TRIALS

The works trials described here were concerned with measuring the use made of the notches of the long-travel controller of a stripper crane during the crane's normal working.[9] Existing long-travel controllers are provided with a varying number of notches, and if some of these could be shown to be superfluous to the efficient working of the crane, some reduction in the size of the controller could be brought about. This reduction in size would make possible an improved layout of the controls, would benefit accessibility and visibility of the cab, and would reduce primary and maintenance costs. Four different stripper cranes in four different steelworks were studied in the series of trials described.

The equipment used on the trials consisted of a paper-tape perforator and an associated box of relays. The relays and the perforator coils were connected across the coils of the contactor panel of the long-travel motion of the crane so that all the time the controller was in a particular notch a particular coding of holes associated with that notch was punched in the tape. The coding allowed for the direction of the notch also to be distinguished. The perforator was allowed to run unattended during the trial and an auto-switch was provided to switch off when the crane ceased operation for any period longer than 8 s. The perforator would then automatically begin to record as soon as the crane resumed work.

On all four cranes the recording period covered all three shifts and the total periods in each case ranged between 30 and 50 h operation of the crane. Recording was continuous on each crane except for two delays because of maintenance on two of the cranes. The controllers studied were provided with notches as follows:

*Works A*: 4 speeds in each direction
*Works B*: 6 „ „ „ „
*Works C*: 4 „ „ „ „
*Works D*: 5 „ „ „ „

In the trials at works *A*, probably because of some unrealized feature on the contactor panel, the apparatus failed to distinguish between use made of the third and fourth notches, so that these had to be considered together in the results.

Analysis of the results of the trials gave two measures concerning the use of the notches. These were the total time spent in each notch during the recording period, and the frequency with which each notch was used. Analysis of the results required a decision upon a point of principle occasioned by the following consideration. Because of the electro-mechanical design of the controller, all movements of the handle cause the contactor circuits to be made or broken in strictly ascending or descending order. Thus, to use notch 5 the controller must pass through notches 1, 2, 3, and 4. Time spent in these notches would be brief but nevertheless might be recorded, so that the results would be unduly weighted for the

intermediate notches because of the number of these brief appearances on the tape.

It was eventually decided to take into account only those occasions in which the notch was used for 0·5 s or more. This figure was reached after a series of preliminary analyses of the tapes in which various criteria from 0·1 to 0·5 s were used.

The distributions of the percentage times and frequencies for which each notch was used was worked out for each crane studied and these were compared with the distribution that would have occurred had each notch been used equally. It was found in all cases that the distribution obtained differed significantly from the 'expected' distribution. Results for individual cranes were as follows.

In *works A* the first notch was the most used in terms of time and frequency of use. The average length of time spent in this notch was small compared with the other notches, showing it was mainly used for inching. The frequency of use of notches 3 and 4 together was small, showing that they could well be combined.

In *works B* the most used notch was again the first, which was mainly used for inching, with the sixth notch used less frequently but for lengthy periods for travelling. The intermediate notches were used very infrequently and for short periods, showing again that they might well be combined.

In *works C* the most used notches were the intermediate ones. The first notch was probably used infrequently, because the crane did not move when loaded until the controller was in the second notch. If the speeds could be arranged so that, irrespective of load, the crane always moved on the first notch, notches 1 and 2 could probably be combined. The fourth notch was little used because the crane rarely travelled a distance sufficiently long to warrant using a high speed.

In *works D* the first two notches were arranged as at works *C* and the same remarks apply. Notch 5 was used infrequently but was used for fairly long periods. Notch 4 was used infrequently and could probably be eliminated.

From these studies the following conclusions were drawn:

(1) On a crane which always moves on the first notch, whether loaded or not, and where the length of the shop allows the crane to get into its maximum speed, the intermediate notches are used less frequently than the first and last notches.

(2) There was considerable evidence from the four cranes tested that some reduction in the number of notches was possible. This could be effected with no loss of smoothness of control, since the number of starting steps on the resistors would not necessarily be reduced.

(3) When a particular controller is being installed, more thought should be given to considering the number of notches necessary and perhaps trials, such as those described above, carried out.

Following upon these four trials, a six-notch long-travel controller was removed from a stripper crane in one of the works and replaced by a three-notch controller. Conversations with the drivers concerned and a before-and-after study of the crane's production records showed that the crane performed its job adequately with the three-notch controller fitted.

## CONCLUSIONS

The laboratory experiments described have been concerned with measuring objectively the operating efficiency of hand and foot controllers relative to certain aspects of their design. The results obtained provide a quantitative basis upon which the design of actual controllers can be based. Two general points, however, need to be made about the conclusions quoted.

(1) The results were obtained in a laboratory situation in which time was the only criterion of efficiency. Only one motion was controlled and so the subjects did not have to take their hand or foot off the controller at any time during the test. The results are possibly specific to the laboratory situation, and for this reason, and because factors other than speed of operation (e.g. safety) may have to be considered, the conclusions need testing in an actual works situation.

(2) For the experiments to be practicable as regards the apparatus and time available, it was necessary to test the design variables at certain discrete levels rather than as continuously variable quantities. The results must therefore be interpreted as providing a quantitative comparison only between levels actually tested of the variables; they do not preclude the possibility that in some cases a better level exists outside this range. The levels were, of course, carefully selected to provide practicable settings of the controller.

With these two points in mind the recommendations for the design of master controllers are summarized thus:

*Foot Controllers*

(1) The pivot should not be more than 1 in. above nor more than 2 in. below the pedal; it should be some 5 in. in front of the back of the pedal.

(2) Two or three speed-steps in each direction are preferable to four speed-steps.

(3) An operating torque (measured at the front of the pedal) of 30–60 lb-in. is preferable to 72 lb-in.

(4) 40° to 50° angular separation between extreme positions is slightly preferable to 30°.

*Hand Controllers*

(1) Four speed-steps in each direction are preferable to three or six speed-steps.

(2) With three or four speed-steps, handle lengths of 9–12 in. are preferable to 15 in.

(3) If six speed-steps have to be used, an arc of movement of 35° or 50° in each direction is preferable to 20°.

(4) A light and smooth feel is preferable to either no feel or to a positive and fairly tight feel.

(5) The controllers should be provided with a mechanism giving extra location for the off-position.

(6) Provision of a mechanical safety latch for the off position does not affect operating efficiency.

The works trials described showed that the use made of the notches of the long-travel controller of a stripper crane depended upon the rating of the first two speed-steps relative to the load of the crane and whether the length of the shop was such as to enable

the crane to achieve its maximum speed. The trials show that a reduction in the number of notches is possible as a means of reducing the size of the controller and this does not impair the efficiency of the crane. The main conclusion from these trials is that, when a particular controller is being installed in a crane, more thought should be given to the number of speed-steps necessary.

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### References

1 "Crane Specification for Heavy-Duty Electric Overhead Travelling Cranes for Use in Iron and Steelworks": 1955, London, B.I.S.R.A.
2 L. N. Bramley: *J.I.S.I.*, 1953, vol. 173, pp. 53–68.
3. J. A. Samuel: B.I.S.R.A. unpublished report no. PE/N/3/55.
4. R. G. Sell and J. Knight: *Ibid.*, no. PE/N/96/56.
5. J. A. Samuel and L. N. Bramley: *Ibid.*, no. PE/B/79/54.
6. J. A. Samuel and R. G. Sell: *Ibid.*, no. PE/N/12/55.
7. A. Box and R. G. Sell: *Ibid.*, no. PE/NE/83/58.
8. A. Box: *Ibid.*, no. PE/NE/50/57.
9. R. G. Sell and N. C. Motts: *Ibid.*, no. PE/N/13/56.

# The Plane-frame Method of Analysis for Lattice Girders

*By R. G. Tyler, B.Sc.(Eng.), A.M.Inst.C.E.*

SYNOPSIS

For the girders of E.O.T. cranes and gantries which are subject to both vertical and horizontal loadings, a structure is required which has stiffness both in its depth and laterally. Where the girder is wholly or partly lattice construction, a space-frame analysis may be employed, the method of plane frames, whereby the structure is split up into plane frames, being the most convenient method of design.

For steelworks structures subject to dynamic loads it is desirable that the applied loads shall be resisted by primary action only, joints being assumed pinned in design and only direct forces in members being calculated. The relationships connecting the number of joints to the number of bars for 'complete' or 'just-stiff' frameworks are given, the characteristic of these frameworks being that they are capable of resisting any system of loading by their primary action.

The various types of girder are split up into plane frameworks and the loadings in each plane computed by consideration of the equilibrium of the joints, each longitudinal chord member being common to two frameworks. Where two chord members are not braced in the manner of a plane framework, but are merely connected by spacing members, the structure is incapable of carrying load in that plane by primary action.

Deflection diagrams are drawn, these being derived from the deflections associated with each plane framework estimated from the Williot–Mohr diagram. Where two chord members are only connected by spacing members, deflection in that plane is indeterminate unless fixed by the remainder of the structure.

The characteristics of the various types of girders as determined from the space frame analysis are as follows:

Types I and II are simple plane frameworks unstable under lateral loading (types I–X are shown in Figs. 1–10).

Types III and V are triangular-sectioned girders unstable because of indeterminate deflection in one plane.

Types IV and VI are triangular-sectioned girders, capable of resisting any system of loading by their primary action. They would be suitable for use in gantries where the box section is not required for housing electrical equipment, subject to the practical difficulties of the fabrication of joints in the inclined plane being overcome.

Type VII is a girder exhibiting some instability together with distortion in the plane of the cross-section for normal riveted joints, which disadvantage can be overcome by the use of truly pinned joints in the plane of the cross-section.

Type VIII is similar to type VII except that the instability is eliminated by the addition of bottom boom bracing. The cross-section would need to be articulated as for type VII.

Type IX is a box girder capable of resisting loads in the plane of the cross-section, but inefficient compared with type X, since only the main and floor trusses carry the rail loadings. It also has an excessive bottom boom deflection characteristic.

Type X is the box section used for E.O.T. cranes. It is redundant to the $n - 1$ degree where $n$ is the number of panels, and is capable of resisting any system of loads by its primary action. The 'Deflection Method' enables the forces in the members to be determined. The structure is efficient in that forces are induced in all the members by rail loadings, and behaves in the manner of a composite beam.

Comparison of deflections between girder types IV, VII, VIII, and IX on the one hand and type X on the other shows that, whereas the type X possesses greater lateral rigidity as indicated by the range of lateral movement at the rail, its deflection characteristic is predominantly inwards tending to shorten the span, the amount of this inwards movement being about 20% greater than for the other types.

Further work is needed to establish the effect on rail wear of the lateral deflection of rail members for the various girder types, particularly in relation to other deflections arising from column, foundation, or building movement.

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## INTRODUCTION

THE OPERATION OF E.O.T. cranes gives rise to both vertical and horizontal loads on crane bridges and gantries, and to resist these loads some form of girder must inevitably be employed which has stiffness both in its depth and laterally. Frequently an I beam or a plane truss will suffice, but where the horizontal surge loads are sufficient to cause excessive lateral deflections an auxiliary structure is added to resist these loads.

For the wholly lattice-type structure a space-frame analysis may be used, while the theory of beams under combined bending and torsion will hold for a boxed-plate construction. Frequently, however, crane and gantry girders are a combination of the two types, built-up I beams being employed with lattice auxiliaries. Space-frame analysis may be applied to such structures in the manner indicated in this paper. Stresses will inevitably be determined less accurately than for a true framework, but the method is simple, readily applicable to drawing-office use, and will give structural design on the side of safety.

While the analysis of a statically determinate space-frame is not difficult, it may be inconvenient from the drawing-office viewpoint in that the structure must be visualized in three dimensions. In the case of steelworks cranes and gantries, however, the structure can usually be split into plane frames in the manner indicated by Timoshenko and Young[1] and a simple analysis follows.

The present paper is written as a companion to "Structural Design of Steelworks E.O.T. Cranes"[2] in which the method of plane frames is used for the solution of the normal type of box construction used for E.O.T. cranes. In this paper the advantages and disadvantages of a number of girders are considered in relation to their suitability for steelworks cranes and gantries.

## PRINCIPLES OF DESIGN

### General

For steelworks structures subjected to dynamic loading it is desirable that the applied loads should be resisted by primary action only, i.e. by direct forces in the members, all joints being assumed pinned in design. The joints will in practice possess rigidity but in the event of vibration loosening bolts or rivets the structure will return to the pinned design condition. The joint stiffnesses will add stiffness to the structure as a whole which will be neglected in this paper. This stiffness will reduce the primary stresses, but the B.I.S.R.A. series of tests on E.O.T. cranes has shown that simple methods of calculation such as those used in this paper enable a fair estimation of primary stresses to be made. If desired, joint stiffnesses may be allowed for by use of the Williot–Mohr deflection diagram and the Hardy–Cross Distribution Method, but the analysis is too complex for drawing-office use, and an accurate solution is unobtainable since the joint stiffnesses will vary depending on whether the structure is welded, riveted, or bolted.[3]

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### Characteristics of Frameworks

A plane framework will be capable of resisting any system of loads applied in its own plane provided that it is composed of just sufficient bars to divide it into triangles. The following relationship holds for a plane framework:

$$n = 2p - 3$$

where $n$ is the number of bars, and $p$ the number of joints.

Generally a space framework will be capable of resisting any system of loads provided the relationship holds:

$$n = 3j - 6$$

where $n$ is the number of bars, and $j$ the number of joints. Such a framework is shown in Fig. 4*a*.

Figure 4*b* shows a framework similar to that in Fig. 4*a* but with a number of joints a, b, etc., which are coplanar only, included to give additional support to vertical loads on rail member A. In this framework an additional bar is inserted over the type in Fig. 4*a* for each coplanar joint, and the following relationship holds for a complete space frame, which the type in Fig. 4*b* satisfies:

$$n = 3j - 6 + 2p$$

where $n$ is the number of bars, $j$ the number of joints where the axes of the bars do not lie in one plane (A, B, C, etc.), and $p$ is number of coplanar joints (a, b, c, etc.).

Where an I beam is incorporated in the structure as in Fig. 4*c* it can be regarded as equivalent to any main truss such as those in Fig. 4*a* and 4*b* since any triangulation of members can be imagined within the web. The structure will therefore resist any system of loads applied to its joints, and owing to the presence of the I beam will be particularly efficient in distributing wheel loads to the joints.

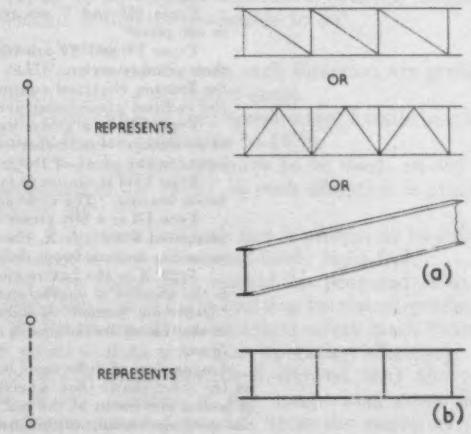


**Fig. 1—Details of notation used in subsequent cross-section line diagrams**

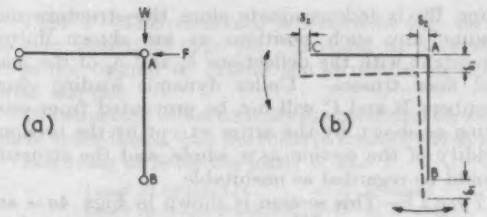


Fig. 2—Type II girder

## APPLICATION OF DESIGN PRINCIPLES TO GIRDER TYPES

### General

A number of types of girder are considered in detail in the light of the above design principles, and their advantages and disadvantages outlined. Figures 1*a–b* give the details of the notation used in subsequent cross-section line diagrams. Figure 1*a* gives the symbol representing a plane triangulated framework or I beam capable of resisting loads in its own plane, while Fig. 1*b* gives the symbol for two chord members separated by spacers only, an arrangement which will be incapable of resisting loads in its own plane by its primary action. In the following it is assumed that the ends of the main trusses or I beams are adequately and simply supported on columns top and bottom.

*Type I*—This type is the plane framework or I beam

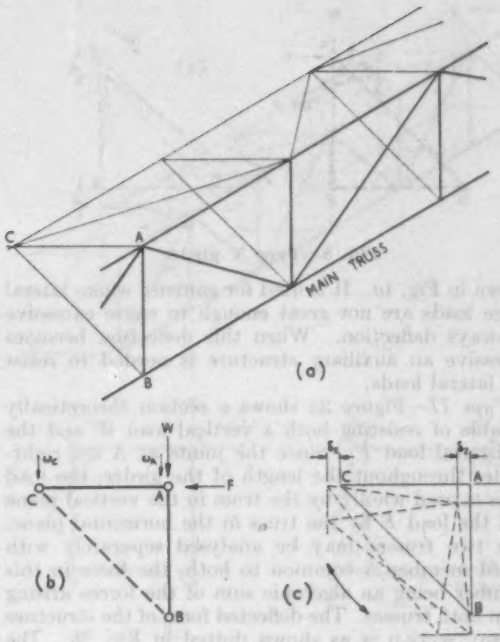


Fig. 3—Type III girder

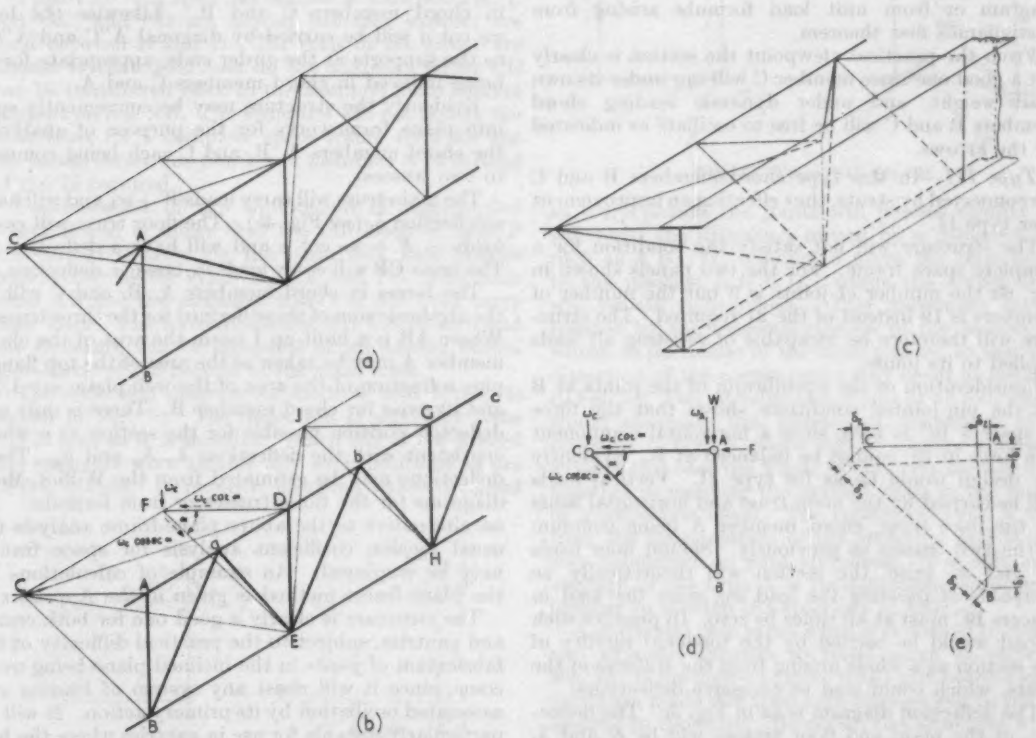


Fig. 4—Type IV girder

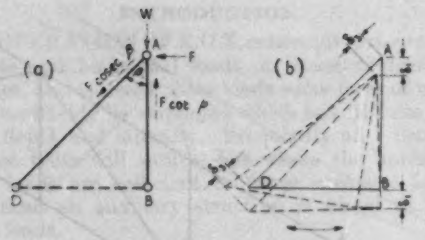


**Fig. 5—Type V girder**

shown in Fig. 1*a*. It is used for gantries where lateral surge loads are not great enough to cause excessive sideways deflection. When this deflection becomes excessive an auxiliary structure is needed to resist the lateral loads.

*Type II*—Figure 2*a* shows a section theoretically capable of resisting both a vertical load $W$ and the horizontal load $F$. Since the joints at A are right-angles throughout the length of the girder, the load $W$ is carried wholly by the truss in the vertical plane and the load $F$ by the truss in the horizontal plane. The two trusses may be analysed separately with chord member A common to both, the force in this member being an algebraic sum of the forces arising from both trusses. The deflected form of the structure at any section is as shown dotted in Fig. 2*b*. The chord member A will suffer two displacements, one at right-angles to the other, which will be the displacement of the two trusses under loads $W$ and $F$ respectively, estimated from the Williot–Mohr deflection diagram or from unit load formulæ arising from Castigliano's first theorem.

From the practical viewpoint the section is clearly not a good one since member C will sag under its own dead weight, and under dynamic loading chord members B and C will be free to oscillate as indicated by the arrows.

*Type III*—In this type chord members B and C are connected by struts, thus effecting an improvement over type II.

The structure will not satisfy the condition for a complete space frame. For the two panels shown in Fig. 3*a* the number of joints is 9 but the number of members is 19 instead of the 21 required. The structure will therefore be incapable of resisting all loads applied to its joints.

Consideration of the equilibrium of the joints at B for the pin-jointed conditions shows that the force in spacers BC is zero, since a horizontal component of a force in BC cannot be balanced at B. Evidently the design would be as for type II. Vertical loads will be carried by the main truss and horizontal loads by the floor truss, chord member A being common to the two trusses as previously. Should floor loads $w_A$ and $w_C$ arise, the section will theoretically be incapable of resisting the load $w_C$, since the load in spacers BC must at all times be zero. In practice such a load would be carried by the torsional rigidity of the section as a whole arising from the stiffness of the joints, which could lead to excessive deflections.

The deflection diagram is as in Fig. 3*c*. The deflection of the main and floor trusses will be $\delta_1$ and $\delta_2$ respectively as for type II. The deflection in the plane BC is indeterminate since the structure may assume any such positions as are shown dotted, consistent with the deflections $\delta_1$ and $\delta_2$ of the main and floor trusses. Under dynamic loading chord members B and C will not be prevented from oscillating as shown by the arrow except by the torsional rigidity of the section as a whole, and the structure should be regarded as unsuitable.

*Type IV*—This section is shown in Figs. 4*a–e* and is similar to type III except that bracing has been added in plane BC. It has already been shown (p. 188) to satisfy the condition for a complete space frame and will resist any system of direct loads applied to its joints.

Under loads $W$ and $F$ only (Fig. 4*d*), consideration of the equilibrium of joints along chord members B and C shows that the force in all members in plane BC is zero since a vertical component of any load in plane BC cannot be balanced at C except by an externally applied force, and likewise a horizontal component cannot be balanced at B. Evidently main truss AB will carry the load W and the floor truss AC will carry the load F as for types II and III.

Floor loads $w_A$ and $w_C$ will both be carried by the primary action of the pin-jointed structure.

Resolving at joint C:

$$\text{Load in CB} = w_C \operatorname{cosec} a$$
$$\text{Load in CA} = w_C \cot a$$

Considering the horizontal equilibrium of the joint at B′ Fig. 4*b* shows that the load $w_C$ cosec $a$ is carried by such diagonals as B′C and B′C″ to the supports at the girder ends, appropriate forces being induced in chord members C and B. Likewise the load $w_C$ cot $a$ will be carried by diagonal A″C and A″C″ to the supports at the girder ends, appropriate forces being induced in chord members C and A.

Evidently the structure may be conveniently split into plane frameworks for the purpose of analysis,[1] the chord members A, B, and C each being common to two trusses.

The main truss will carry loads $W + w_A$ and will have a deflection $\delta_1$ (*see* Fig. 4*e*). The floor truss will carry loads $\pm F + w_C$ cot $a$ and will have a deflection $\delta_2$. The truss CB will carry loads $w_C$ cosec $a$, deflection $\delta_3$.

The forces in chord members A, B, and C will be the algebraic sum of those derived for the three trusses. Where AB is a built-up I beam the area of the chord member A may be taken as the area of the top flange, plus a fraction of the area of the web plate, say 1/10, and likewise for chord member B. There is only one deflected position possible for the section as a whole consistent with the deflections $\delta_1$, $\delta_2$, and $\delta_3$. These deflections may be estimated from the Williot–Mohr diagrams for the three trusses or from formulæ. As an alternative to the above plane-frame analysis the usual tension coefficient analysis for space frames may be employed. An example of calculations by the plane-frame method is given in the Appendix.

The structure is clearly a good one for both cranes and gantries, subject to the practical difficulty of the fabrication of joints in the inclined plane being overcome, since it will resist any system of loading and associated oscillation by its primary action. It will be particularly suitable for use in gantries where the box section is not required to house electrical equipment.

*Type V*—This structure is shown in Fig. 5*a* and is very similar to type III. It could be used where it is not desired to extend the structure on a level with the rail.

The structure will not satisfy the condition for a complete space frame, and the force in spacers BD is zero.

Resolving at A for the loads $W$ and $F$

Load in truss AD $= \pm F$ cosec
Load in main truss AB $= W \pm F$ cot.

The deflected form is shown in Fig. 5*b*, $\delta_1$ and $\delta_2$ being the deflections of the two trusses under their respective loads. The bottom member of the main girder is not prevented from oscillating by the primary action of the structure since BD can take up any such positions as are shown dotted consistent with the deflections $\delta_1$ and $\delta_2$. A further disadvantage is that lateral surge will increase the load on the main girder when acting away from the structure.

*Type VI*—This structure is shown in Fig. 6*a*. It is an improvement over type V and is similar to type IV, in that it satisfies the conditions for a complete space frame.

The loads and deflections on trusses AB and AD will be as for type V, with the improvement that the bottom of the main girder will be prevented from oscillating by the primary action of truss BD. The structure has the same disadvantage as type V however, since the load on the main girder will be increased when the lateral surge acts away from the structure. It could, however, be used for gantries where space does not permit of a floor at rail level.

*Type VII*—An open box-section is shown in Fig. 7. AB, AC, and CD are braced but only spacers are used between B and D. The ends of the girder are braced so that dead load on the auxiliary girder CD can be transferred back to the assumed main column support on line AB. The structure will not satisfy the conditions for a complete space frame since for the six panels shown the number of members is 72 instead of the 78 required.

Consideration of the equilibrium of right-angled joints B and C shows that the rail loads $W$ and $F$ are carried entirely by the main and floor trusses respectively as for types II, III, and IV. The main truss AB and the auxiliary truss CD will both carry floor loads. The force in spacers BD will be zero and the structure will be incapable of preventing lateral movement of the bottom of the main truss.

The deflection diagram for loads $W$ and $F$ only is shown in Fig. 7*c*. The deflection of auxiliary truss CD is zero as it is inactive. Since BD is not braced the structure may assume any such positions as are shown dotted. In practice, however, unless designed

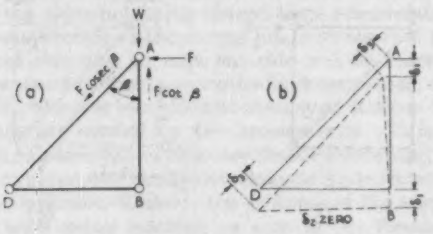


Fig. 6—Type VI girder

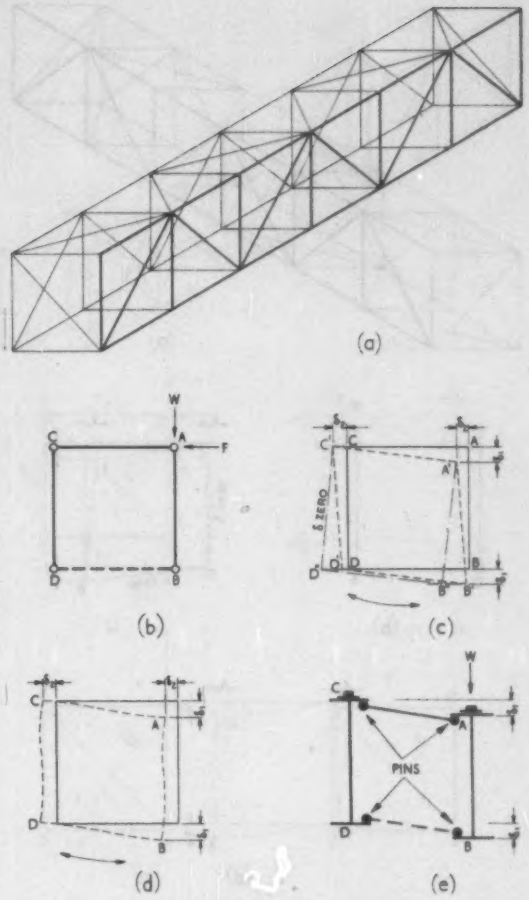


Fig. 7—Type VII girder

as truly pinned the joints will possess rigidity and will resist the distortion caused by a deflected form such as A′B′C′D′, tending to move the cross-section to the position A′B″C′D″, where the corner angles will remain right-angles. This movement may be resisted by the torsional rigidity of the section as a whole, in particular of the main girders, so that some distortion of the corner joints may occur as indicated in Fig. 7*d*. The introduction of pins at all four corners would eliminate this effect, but conversion of the structure to type X might well be a better alternative since in this case the whole of the cross-section works together in resisting the applied loads in the manner of a composite beam. The rigidity of type X arises from the triangulation of the structure and is in no way dependent on joint stiffnesses. The only disadvantage of the type X is its deflection characteristic tending to shorten the span (*see* p. 193).

A particular case arises when it is desired to connect two adjacent gantries to resist surge as shown in Fig. 7*e*. If the floor-to-girder joints and bottom spacer joints are made stiff then high stresses will be induced leading to fractures. However, the structure will be satisfactory if it is articulated as shown in Fig. 7*e*, the joints being designed as truly pinned.

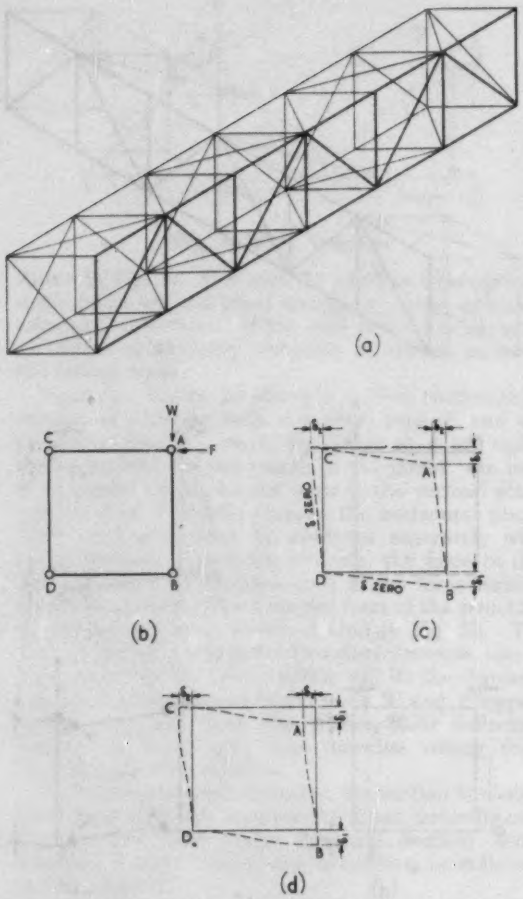


**Fig. 8—Type VIII girder**

*Type VIII*—A further possible type of box section is shown in Fig. 8, differing from type VII in that the bottom boom DB is braced. The structure will satisfy the condition for a complete space frame, the number of members for the two panels shown being 78 for 28 joints. It will therefore resist any system of loads applied to its joints by its primary action. The live loads $W$ and $F$ will be taken by the main and floor trusses respectively and floor loads may be carried both by main truss AB and auxiliary truss CD, as for type VII.

The characteristics of the structure (*see* Figs. 8*c* and *d*) are basically as type VII except that the introduction of bracing to the bottom boom will give stability to the bottom of the main and auxiliary girders. Articulated joints would be needed in the plane of the cross-section as for type VII. The alternative is again a conversion to type X as outlined for type VII.

*Type IX*—This type of box section is shown in Fig. 9 and is similar to type VII except that diagonal spacers are inserted between chord members C and B. The structure will not satisfy the condition for a complete space frame. For the six panels shown in Fig. 9*a* the number of members is 77 when the number required is 78.

Considering the equilibrium of joint D it is evident that the load in spacers BD is zero. Likewise the load in diagonal BC is also zero, since zero load in spacers BD requires a zero horizontal component in diagonal BC.

As for types V and VI the live loads $W$ and $F$ will be taken by the main and floor trusses respectively and floor loads by the main girder AB and the auxiliary truss CD.

The deflection diagram Fig. 9*c* is shown for loads $W$ and $F$ only, and is drawn for the following conditions:

| | |
|---|---|
| Deflection of main truss AB under load $W$ | $= \delta_1$ |
| Deflection of floor truss AC under load $F$ | $= \delta_2$ |
| Deflection of auxiliary truss CD | = zero since it will be maintained as such by its primary action. |

Diagonal BC is unchanged in length. There is no distortion in the plane of the cross-section, hence the main disadvantage of type VIII with normal riveted joints is eliminated. Since there is only one deflection position for the cross-section, oscillation of the bottom member of the main truss will be prevented. The structure is, however, inefficient since only two trusses are loaded by the loads at the rail member. Also, in Fig. 9*c* the deflection of the bottom boom is seen to be the sum of the deflection of the top boom and main girder.

*Type X*—Figures 10*a–e* show the well known structure used for E.O.T. cranes. It is redundant to the $n - 1$ degree where $n$ is the number of panels in the

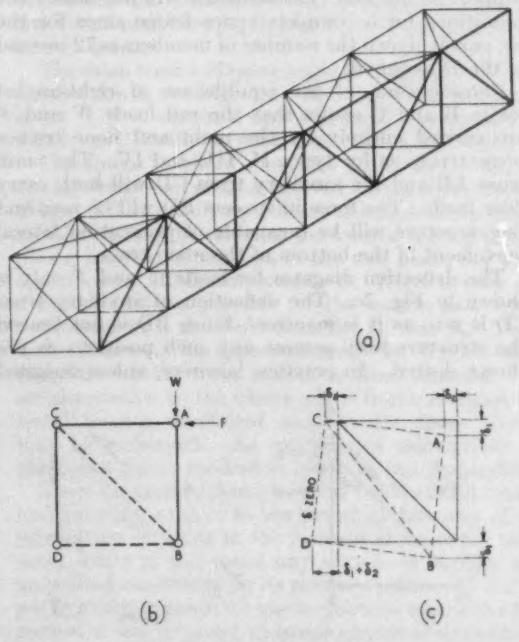


**Fig. 9—Type IX girder**

length of the girder. In Fig. 10*a* six panels are shown so that the number of redundancies is five, the number of members being 83 when only 78 are required.

The structure will resist any system of direct loads applied to its joints by its primary action and a solution of the type of structure employing a truss for a main girder may be obtained by using the principles of strain energy. However, the solution is long and tedious and is unsuitable for drawing-office use.

The Deflection Method[2] is an approximate method which has so far given good results when checking measured stresses on E.O.T. cranes. It enables the section to be split up into the four trusses AB, CD, AC, and BD, each of the chord members being assumed common to two adjacent trusses. Owing to applied loads $W$ and $F$ on the bridge rail, loads $X_1$, $X_2$, $X_3$, and $X_4$ will be induced in the four trusses as shown in Fig. 10*b*, and each truss may be designed for its appropriate load, the forces in chord members being the algebraic sum of those derived from two adjacent trusses.

The structure will behave as a composite beam and loads applied to any one corner of the section will cause all four trusses to be loaded. Load transfer is affected by the cross bracings CB, the maximum transfer occurring near the point of application of the load. Considering the equilibrium of the joint D indicates that ratio $X_2 : X_4 = d : b$ for the ideal pin-jointed condition. This result is substantiated by calculations made by the Deflection Method for the usual square section, when $X_2 = X_4$ approximately.

Where the lateral load $F$ acts towards the girder as in Fig. 10*d* a maximum stress will occur in chord member D, while when load $F$ acts away from the girder (Fig. 10*c*) a maximum stress will occur in chord members C. The resultant load $R$ on the section is shown for each case. Resultant $R$ may be replaced by a load $R'$ at the rotational centre O, together with twist on the section. The twist can be shown to have little effect on the forces in chord members, but treating the section as a composite beam it can be seen that for $F$ acting inwards $R'$ will cause bending about an axis roughly parallel to diagonal CB, giving a maximum stress in bottom member D, while for $F$ acting outwards bending will roughly take place about axis AD giving a maximum stress in top member C.

The type of deflection obtained is as shown in Fig. 10*c* and it is seen that the girder section is displaced as a whole indicating that there are no secondary stresses in the plane of the cross-section. Evidently this type of structure is a good one as has been shown by its almost universal adoption for crane bridges. Its efficiency depends on all four sides AB, BC, CD, and DB being braced. In the event of any one of the sides not being braced then consideration of the equilibrium of the corner joints shows that the unbraced side and an adjacent side will be inactive and the structure becomes statically determinate, e.g. type IX, which is less efficient than type X since the rail loads are carried by two trusses only. It is of interest to note that in this case the structure may be solved either as a statically determinate space frame or by the Deflection Method, the stiffness of the appropriate truss being inserted as zero in the formulæ. Identical results are obtained by the two methods.

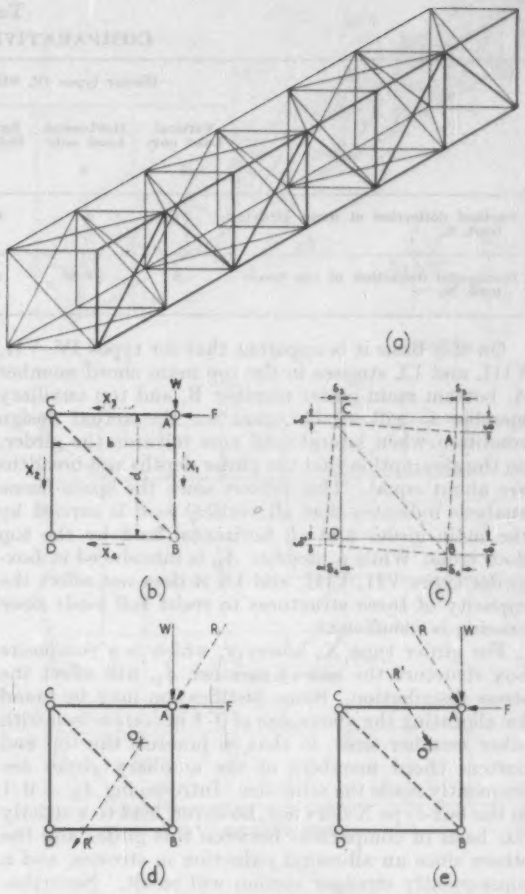


**Fig. 10—Type X girder**

### Comparative Deflections of Girder Types

While girders of the types already discussed may be designed to any given deflection characteristics within the limitations of the girder type, comparative deflections are nevertheless of interest for girders having the same member sizes, since the amount of rail wear will depend largely on the lateral movement of the rail.

It is proposed in the following to compare the deflection characteristics of girder types IV, VII, VIII, and IX collectively on the one hand and the girder type X on the other. Girder type VI is not included since it is not so frequently used owing to the necessity of providing a walkway on the gantry or crane.

For a vertical wheel load $W$ and a lateral load $F$, assumed equal to $1/10W$, acting either towards or away from the girder, comparison may be made by assigning chord member areas as follows:

$A_A = 1{\cdot}1$ units
$A_B = 1{\cdot}0$ ,,
$A_C = 0{\cdot}1$ ,,
$A_D = 0{\cdot}1$ ,,

where $A$ is the area of a member and suffixes A, B, C, and D refer to the appropriate chord members.

**Table I**
**COMPARATIVE DEFLECTIONS**

| | Girder types IV, VII, VIII, IX | | | | Girder type X | | | |
|---|---|---|---|---|---|---|---|---|
| | Vertical Load only | Horizontal Load only | Range of Deflection | Maximum Deflection | Vertical Load only | Horizontal Load only | Range of Deflection | Maximum Deflection |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Vertical deflection of main girder load, $X_1$ | +1 | 0 | 0 | +1 | +0·96 | ±0·025 | 0·05 | +0·98 |
| Horizontal deflection of top boom load, $X_2$ | 0 | ±0·57 | 1·14 | ±0·57 | −0·25 | ±0·43 | 0·86 | −0·68 |

On this basis it is apparent that for types IV, VII, VIII, and IX stresses in the top main chord member A, bottom main girder member B, and top auxiliary member C will all be equal for the actual design condition when lateral load acts towards the girder, on the assumption that the girder depths and breadths are about equal. This follows since the space-frame analysis indicates that all vertical load is carried by the main girder and all horizontal load by the top floor truss. While a member $A_D$ is introduced in box-girder types VII, VIII, and IX it does not affect the capacity of these structures to resist rail loads since bracing is insufficient.

For girder type X, however, which is a composite box structure the size of member $A_D$ will affect the stress distribution. Some justification may be found for allocating the above size of 0·1 in comparison with other member sizes, in that in practice the top and bottom chord members of the auxiliary girder are frequently made the same size. Introducing $A_D = 0{\cdot}1$ to the box-type X does not, however, lead to a strictly fair basis of comparison between this girder and the others since an all-round reduction in stresses, and a consequently stronger section will result. Nevertheless bearing this in mind, comparative deflections between type X and the types IV, VII, VIII, and IX are of interest.

*Deflection Formulæ*—For all girder types:

$$\text{Vertical deflection of rail} = \text{vertical deflection of main girder} = \frac{kX_1}{I_1}$$

$$\text{Horizontal deflection of rail} = \text{horizontal deflection of top boom} = \frac{kX_2}{I_2}$$

where $I_1$ and $I_2$ are the second moments of area of the main girder and top boom respectively when taken as simple beams made up of chord areas only. $X_1$ and $X_2$ are the truss loads in the main and auxiliary girders respectively as indicated in Fig. 10*b*, and $k$ is a constant depending on the span, position of loads, etc.

In the case of trusses, taking deflections as inversely proportional to second moments of area of the two chord members would lead to calculated deflections up to 20% less than true deflections, since the triangulation of the structure is neglected. For this paper, however, the procedure is sufficiently accurate for obtaining comparative deflections of girders.

Taking second moments of area

$$I_1 = \frac{A_A \cdot A_B}{A_A + A_B} d^2 = \frac{1 \cdot 1}{2 \cdot 1} d^2$$

$$I_2 = \frac{A_A \cdot A_C}{A_A + A_C} b^2 = \frac{0 \cdot 11}{1 \cdot 2} b^2$$

Let $b = d$ as previously assumed and take $I_1$ as unity, then:

$$I_2 = \frac{0 \cdot 11}{1 \cdot 2} \times \frac{2 \cdot 1}{1 \cdot 1} = 0{\cdot}175.$$

Hence

Vertical deflection of rail member $\propto X_1$

Horizontal ,, ,, ,, ,, $\dfrac{X_2}{0 \cdot 175} \propto 5{\cdot}7X_2$.

*Value of truss loads $X_1$ and $X_2$ for types IV, VII, VIII, and IX*—Since all vertical load is carried by the main girder and all horizontal load by the top boom

$$X_1 = W$$
$$X_2 = \pm F$$

*Value of truss loads $X_1$ and $X_2$ for type X*—For this type the truss loads may be obtained by the Deflection Method.[2] The constants employed in this method become:

$$C = A_A A_B A_C + A_A A_B A_D + A_A A_C A_D + A_B A_C A_D = 0{\cdot}241$$

$$K_1 = \frac{A_A A_B (A_C + A_D)}{C} = 0{\cdot}913$$

$$K_2 = \frac{A_C A_D (A_A + A_B)}{C} = 0{\cdot}087$$

$$K_3 = \frac{A_A A_C (A_B + A_D)}{C} = 0{\cdot}502$$

$$K_4 = \frac{A_B A_D (A_A + A_C)}{C} = 0{\cdot}498$$

Hence $X_1$ and $X_2$ are given by:

$$X_1 = \tfrac{1}{2}\left[W(1 + K_1) \pm \frac{d}{b} K_4 F\right] = 0{\cdot}956W \pm 0{\cdot}25F$$

$$X_2 = \tfrac{1}{2}\left[\pm F(1 + K_3) - \frac{b}{d} K_2 W\right] = \pm 0{\cdot}75F - 0{\cdot}043W$$

where negative signs indicate directions of forces opposed to those shown in Figs. 10*a–e*.

*Comparative Deflections*—Using the values given of $X_1$ and $X_2$ derived as shown, and the comparative values of deflection, the deflection table (Table I) may be drawn up, deflections being derived for $W = 1$ and $F = 0{\cdot}1$.

*Comments on Deflections*–It is apparent from Table I that the vertical deflection of the main girder for girder types IV, VII, VIII, IX, and X are very similar.

Columns 2 and 6, however, indicate that whereas the effect of a vertical load only on types IV, VII, VIII, and IX is to produce zero horizontal deflection as a result of primary structural action, the type X shows an inward horizontal deflection towards the moving structure of about 25% of the main girder deflection. Hence the maximum inward deflection of type X as shown in col. 9 is some 20% greater than that for the other types when the effect of lateral load is added.

Hence, if the downward deflection of a pair of box-type X gantry girders is, say, 1 in. under vertical load only, then the span will effectively shorten by ½ in. for girders of the proportion adopted in the calculations, whereas an articulated girder of type VIII will show no lateral movement.

It is to be noted, however, from columns 4 and 8 of Table I, that the range of horizontal deflection of type X is less than that of the other types by some 25%, thus indicating greater rigidity of the section. Its disadvantage is that most of the movement is inwards to the moving structure.

It is apparent that horizontal movement of the rail member of the type X should be taken into account in design and further work is needed to establish the effect on wheel wear.

## CONCLUSIONS

(1) The method of plane frames as a space-frame analysis may be conveniently applied to lattice-type steelworks girders.

(2) For structures with normal joints possessing some rigidity, types IV, VI, and X (Figs. 4*a–b*, 6*a–b*, and 10*a–e*) respectively, are shown to be suitable for use under dynamic loading conditions since:

(i) They are capable of resisting any system of loading by their primary action
(ii) They have determinate deflections under load, and are therefore stable
(iii) There is no distortion in the plane of the cross-section
(iv) The structures are efficient in that the majority of members are loaded by the applied rail loads.

(3) While type X is the box section generally used for E.O.T. cranes, types IV and VI are girders of triangular cross-section which, subject to the difficulty of the fabrication of joints in the diagonal plane being overcome, would be suitable for use in gantries where the box section is not required for housing electrical equipment.

(4) The box sections types VII or VIII will be satisfactory if joints in the plane of the cross-section are articulated, although their overall strength will be less than a type X girder of similar proportions. Type VIII would be used in preference to type VII when it is desired to prevent lateral movement of the bottom of the main and auxiliary girders.

(5) Comparison of deflections between girder types IV, VII, VIII, and IX on the one hand and type X on the other shows that, whereas the type X possesses greater lateral rigidity as indicated by the range of lateral movement at the rail, its deflection characteristic is predominantly inwards tending to shorten the span, the amount of this inwards movement being about 20% greater than for the other types.

(6) Further work is needed to establish the effect on rail wear of the lateral deflection of rail members for the various girder types, particularly in relation to other deflections arising from column, foundation, or building movement.

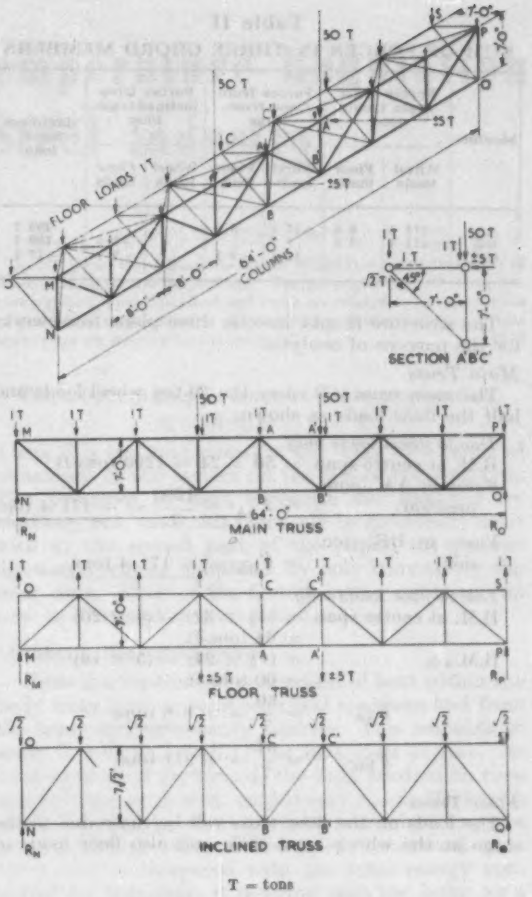


**Fig. 11—Line diagram of triangular-section girder**

## References

1. S. Timoshenko and D. H. Young: "Theory of Structures": 1945, New York, McGraw-Hill.
2. D. Buchanan and R. G. Tyler: *J.I.S.I.*, 1958, vol. 188, pp. 371–388.
3. I. E. Madsen: *Iron Steel Eng.*, 1941, vol. 18, Nov., pp. 47–95.

## APPENDIX

### Calculations by Plane-frame Method

Calculations are carried out for a triangular-section girder type IV. A line diagram of the girder is shown in Fig. 11. The span is 64 ft 0 in. The two wheel loads are 50 tons at 16-ft centres.

The associated lateral surge is 5 tons at each wheel acting either way. Dead loads are applied to a plate floor, 1 ton being carried at each joint.

The forces in chord members AA′, BB′, CC′, will be calculated for the wheel loads at centre span, with the surge acting either way.

**Table II**

**SUM OF FORCES IN THREE CHORD MEMBERS**

| Member | Forces from main truss, tons | | Forces from floor truss, tons | | Forces from inclined truss, tons | | Maximum force, tons |
|---|---|---|---|---|---|---|---|
| | Wheel loads | Floor loads | Wheel loads | Floor loads | Wheel loads | Floor loads | |
| AA′ | −171·4 | −8·6 | ±17·1 | −8·6 | ... | ... | −205·7 |
| BB′ | +171·4 | +9·1 | ... | ... | ... | +8·6 | +189·1 |
| CC′ | ... | ... | ±17·1 | +9·1 | ... | −9·1 | ±17·1 |

The structure is split into its three plane frameworks for the purpose of analysis.

*Main Truss*

The main truss will carry the 50-ton wheel loads and half the floor loads as shown.

*Due to wheel loads only*

B.M. at centre span $= 50 \times 24 = 1200$ tons-ft

Force in AA′ (compression) $= F_{AA'} = \frac{1200}{7} = \underline{-171{\cdot}4 \text{ tons}}$

Force in BB′ (tension) $= F_{BB'} = \underline{+171{\cdot}4 \text{ tons}}$

*Due to floor loads only*

B.M. at centre span $= (4\frac{1}{2} \times 32) - (4 \times 20)$
$= 64$ tons-ft

B.M.$_{A'B'}$ $= (4\frac{1}{2} \times 24) - (3 \times 16)$
$= 60$ tons-ft

$F_{AA'} = \frac{60}{7} = \underline{-8{\cdot}6 \text{ tons}}$

$F_{BB'} = \frac{64}{7} = \underline{+9{\cdot}1 \text{ tons}}$

*Floor Truss*

The loads on the floor truss will be those due to the surge at the wheels, ± 5 tons, and also floor loads of 1 cot 45°, i.e. 1 ton, at panel points along chord member O S.

*Due to wheel loads only*

B.M. at centre span $= 5 \times 24 = \pm 120$ tons-ft

$F_{CC'} = F_{AA'} = \frac{120}{7} = \underline{\pm 17{\cdot}1 \text{ tons.}}$

*Due to floor loads only*

B.M. at centre span = 64 tons-ft (as for main truss)

B.M.$_{C'A'}$ = 60 tons-ft (as for main truss)

$F_{CC'} = \frac{64}{7} = \underline{+9{\cdot}1 \text{ tons}}$

$F_{AA'} = \frac{60}{7} = \underline{-8{\cdot}6 \text{ tons.}}$

*Inclined Truss*

This will be loaded with floor loads of 1 cosec 45° $= \sqrt{2}$ tons applied at panel points along chord member O.S.

*Due to floor loads only*

B.M. at centre span $= (4\frac{1}{2}\sqrt{2} \times 32) - (4\sqrt{2} \times 20)$
$= 64\sqrt{2}$

B.M. at C′A′ $= (4\frac{1}{2}\sqrt{2} \times 24) - (3\sqrt{2} \times 16)$
$= 60\sqrt{2}$

$\therefore \quad F_{CC'} = \frac{64\sqrt{2}}{7\sqrt{2}} = \underline{-9{\cdot}1 \text{ tons}}$

$\therefore \quad F_{BB'} = \frac{60\sqrt{2}}{7\sqrt{2}} = \underline{+8{\cdot}6 \text{ tons}}$

The forces in the three chord members are summed in Table II.

Forces in the bracing members will be those calculated from each individual truss. In the case of the inclined truss these forces will be small, but in no case should these members be omitted since the stability of the girder as a whole depends on bracing in this plane being present.

If it is desired to replace the main truss by an I beam, then the gross area of the compression flange must be capable of carrying a load of 205·7 tons and the net area of the tension flange a load of 189·1 tons.

# *Forthcoming Conferences*

### U.S. Spectroscopy Symposium

The 10th Annual Symposium on Spectroscopy of the American Association of Spectrographers is being held at Chicago from 1st to 3rd June, 1959. Papers in the field of emission, X-ray, infra-red, Raman spectrometry, and flame photometry are invited; titles should be submitted before 1st November to Theodore H. Zink, c/o Armour Research Foundation of Illinois Institute of Technology, 10 West 35th Street, Chicago 16, Ill., U.S.A.

### Indian Iron and Steel Industry

A symposium on the iron and steel industry in India is being held under the auspices of the National Metallurgical Laboratory, Jamshedpur, from 4th to 7th February, 1959. The scope of the symposium is wide, covering raw materials, physical chemistry of iron production, recent advances in production metallurgy, metalworking techniques, production of alloy and special steels, the present status of the industry in relation to the current Indian five-year plan and world production trends, and the use of by-products.

### Instrumentation and Computation

The Institution of Chemical Engineers, the Society of Instrument Technology, and the British Computer Society are jointly organizing a symposium on "Instrumentation and Computation in Process Development and Plant Design," which will be held in London in the summer of 1959. Enquiries should be sent to The Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

### "Fracture, Fatigue, and Failure"

This is the title of a conference being organized by the British Society of Rheology at the University of Leeds on 8th and 9th January, 1959. Details may be obtained from the Secretary, 52 Tavistock Road, Edgware, Middlesex.

# Human Temperature Regulation and the Steel Industry

*By R. F. Hellon*

SYNOPSIS

**In this paper the deleterious effects of heat on the performance of work in industry are emphasized. The principles of body temperature regulation are described and these are related as far as possible to conditions in steelworks. A programme of research to alleviate heat stress on steelworkers is outlined.** 1619

THERE IS ample evidence to show that the performance of work is adversely affected by hot surroundings. In many industries where heat is given off by the processes in the shops, there is a seasonal drop in output in the summer months when conditions that were acceptable in the winter cease to be so when the external temperature rises. This is the case in steelworks,[1] tinplate works,[2] coal mines,[3] and glass-bottle factories.[4] It has even been reported that non-ferrous foundries may close at midday in the height of summer, because conditions become too hot for sustained work.[5] The reasons for this effect of high temperatures upon the performance of work are complex, but it is hoped to outline some of them in the first part of this paper.

In 1957 the Ergonomics Group of the British Iron and Steel Research Association requested that research should be undertaken in an attempt to alleviate excessive heat stress in the industry, and this work has just begun. In the second part of the paper the application of the principles given in the first part will be discussed in relation to steelworkers, together with the proposed programme of research.

## TEMPERATURE REGULATION

### Thermal Balance

For a man to remain efficient at his work, it is essential that his body temperature should remain within certain narrow limits. If this does not happen, first of all his work output will be affected, and ultimately heat collapse may occur.

The body maintains its temperature by endeavouring to strike a balance between heat gain and heat loss to the surroundings. The chief factors concerned with heat gain are:

(i) Metabolic heat production from chemical processes within the body, particularly those accompanying physical work ($M$)
(ii) Radiation from surrounding objects when these are hotter than skin temperature ($R$)
(iii) Convection from the air when this is hotter than skin temperature ($C$).

The chief factors concerned with heat loss are:

(i) Evaporation of sweat and to a small extent of water from the lungs ($E$)
(ii) Radiation to surrounding objects when these are cooler than skin temperature ($R$)
(iii) Convection to the air when this is cooler than skin temperature ($C$).

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These factors may be combined into an equation:

$$M - E \pm R \pm C = S$$

where $S$ is the heat stored in the body as a result of unbalance of the factors on the left of the equation. The processes of heat exchange are modified by clothing, but, since this point will be specifically dealt with in the second part of the paper, the present discussion will be simplified by only considering the nude man. Each of the factors in the equation can now be discussed in more detail.

### Metabolic Heat Production

There is a continuous production of heat within the body from various basic chemical reactions and from the heart and respiratory muscles. This amounts to some 70 kcal/h (280 B.t.u./h) in a man at rest. As soon as work is performed, the heat production rises and for maximum work output may rise to 600 kcal/h (2400 B.t.u./h) for short periods, a ninefold increase over the resting value. When the external work done by a man is compared with the total energy consumed for that task, it is found that the body, as a machine, has an efficiency of 20–25%. This means that four or five times as much heat is formed as appears in the form of mechanical work.

### Evaporation

The loss of water from the body proceeds continuously and under comfortable conditions takes place only from the lungs and through the skin as insensible perspiration. With a greater need for heat loss, with increasing environmental temperature and/or work, actual sweating begins. The evaporation of sweat is always a channel of heat loss and, when the air and surroundings are above skin temperature, is the *only* mode of heat loss. The importance of this has been realised for many years. Blagden[6] in 1775 reported the exposure of men to temperatures of 120° C (dry heat) in a room where beefsteaks were cooking from the heat of the air. The men's temperatures did not rise. Both high humidity and low air movement impede the evaporation of sweat and the body attempts to counteract this by increasing the area of skin which is wet.[7] As much as 3 litres of sweat per hour can be produced by an acclimatized man (*see* below), although this rate cannot be maintained for very long. If this sweat were evaporated, it would cool the body at about 25 times the rate of resting metabolic heat production.

### Radiation

Like all objects which are at a different temperature from their surroundings, the body exchanges heat by infra-red radiation in accordance with the Stefan-Boltzmann law. Normally, radiation is a channel of heat loss and under comfortable resting conditions accounts for about 45% of the total heat loss. If the person is facing a fire or hot object, radiation may be absorbed on the front of the body and emitted from the back. The skin and most clothing act as 'black-body' radiators, i.e. they absorb practically all infra-red radiation received from the surfaces hotter than themselves. The body is also a good radiator and radiates freely to surrounding cooler surfaces. The amount of radiation received by the body will also depend on the direction of the radiant source. Clearly a hot object at the side of the body will affect a smaller area than if it is placed in front or behind.

### Convection

As with radiation, this channel of heat exchange can be both positive and negative, depending on the air–skin temperature difference. The air movement past a man also affects convective exchange, although this is not a simple proportional effect. Convection from an object like the human body has been found to vary with the square root of wind speed, so that increasing the speed will bring gradually diminishing returns.

### Storage

This term represents the net change in heat content of the body when the mechanisms for maintaining body temperature are unequal to the demand, or more usually, when there is a time lag in adaptation.

### Heat Transfer within the Body

So far, only the mechanisms for heat loss from the surface of the body have been discussed; now the transport of heat within the body must be considered. Heat is produced centrally in the body, and the skin must therefore be cooler than the interior if heat is to pass outwards. Heat is conveyed across this thermal gradient partly by direct conduction through the tissues and partly by the circulation of blood from the interior to the capillary blood vessels in the skin where heat may be lost to the exterior. This second way of transferring heat will be seen later to be of major importance in hot conditions.

Up to the present, the term 'body temperature' has been used without qualification, but strictly the term 'deep body temperature' would be more accurate. The vital organs in the centre of the body, such as the heart, brain, and liver, are all at temperatures close to 37° C (98·6° F) and it is towards the maintenance of this temperature that the heat-regulating mechanisms are devoted. Most of the tissues out to within 1 in. of the skin are also at 37° C, but beyond this the temperature, including that of the skin, can vary considerably.

### Co-ordination of Heat Regulation

Most bodily activities are controlled and co-ordinated by the nervous system, and the mechanisms for heat regulation are no exception. There are nervous receptors which are sensitive to temperature in the skin and at the base of the brain. Changes in temperature stimulate these receptors and produce the appropriate reactions to stabilize the body temperature by, for example, altering the skin circulation or initiating sweating. These reactions are purely automatic or reflex and do not require any conscious effort. In addition, a man may take conscious action to assist his reflex reactions by removing clothing, opening windows, etc.

### Reactions of the Body as a Whole

It is now possible to describe briefly how the temperature-regulating system of the body works in response to changing external and internal conditions. Taking first the changes in external conditions, suppose a resting man is exposed to air temperatures of 20°, 30°, and 40° C with the surroundings at the same temperature and a low humidity.

At 20° C he will start with a deep temperature of 37° C, but his skin temperature will rapidly drop to about 28° C. He will be losing heat mainly by convection and radiation. Within the body the blood vessels supplying the skin will be almost completely closed so that conduction from the interior will be reduced to a minimum. Despite this, heat loss from a resting man will exceed heat production, so that his body temperature will fall. This fall can only be arrested by taking exercise or shivering.

At 30° C the most important change will be an opening of the skin blood vessels, bringing blood at 37° C to the surface, which will now assume a temperature of about 34° C. Heat loss by radiation and convection will still continue but at a slower rate than at 20° C and heat balance will be maintained.

If the temperature is raised to 40° C, a resting man can still remain in heat balance but only by a great increase in evaporation, which is now the only means of losing heat. Radiation and convection will now add heat to the body, since the skin temperature will only have risen to about 35° C. There will be a further increase in blood flow to the skin to convey heat across the reduced thermal gradient between the interior and the exterior. To provide this increased circulation to the skin there must be an increase in the output of the heart. This then is the situation in the resting man.

When work is performed there will a considerable increase in heat production and heat balance will be achieved at 20° C. Active sweating will occur at 30° C to deal with the additional heat load and at 40° C there will be more sweat produced than at rest in the same temperature. Beside the increased blood supply to the skin needed for heat regulation, there will also, at all temperatures, be a demand for greater blood supply by the working muscles. When work is done in the heat, therefore, there is a double demand on the heart to pump additional blood to the skin for heat dissipation and to the working muscles for their functioning.

In summary, the performance of work in hot conditions places a strain on the body (i) because the dissipation of the heat produced as a by-product of the work is impeded and (ii) because blood must be supplied

to both the working muscles and to the skin. The first of these reasons is usually the limiting one as regards heat tolerance.

### Acclimatization

Any person suddenly arriving in the tropics finds that several days are required before he is adapted to his new environment. Similar processes take place with daily exposure in a hot chamber while living in a temperate climate.[8] A greater output of sweat is produced, circulatory strain is reduced, and there is a greater capacity for doing work. Most of these changes are largely completed in the first week of exposure.[9] Once acclimatization has been acquired, it is not permanent. Even after a few days without heat exposure some of the adaptation is lost and after a month it has completely disappeared.[10]

### Age

Until recently little was known of the effects of age on the ability to withstand high temperatures. Evidence has now been obtained[11–13] that the blood supply to the skin of men aged 40 and above is in excess of that in young men and apparently in excess of that needed for heat regulation. The sweat glands become less rapid in response when there is a sudden need for sweat, as on exposure to heat or the start of work in the heat. Over a long period, however, the sweat glands of older men appear able to produce just as much sweat. It is perhaps significant that Richardson[14] has noted a drift away from heavy work among men over 40 in industries where conditions can be hot—e.g. foundries and coal mines.

## APPLICATIONS TO STEELWORKERS

Given a situation where a man has difficulty in dissipating the heat he is producing, there are three possible ways of improving matters: (i) a man can reduce his work rate until one is found which can be performed without ill-effect; (ii) he can work as in a cool environment and take frequent rests—during the rests he may or may not be relieved by another man; (iii) means can be found for reducing the heat stress so that it does not impede normal working. Quite clearly the last alternative is the one of choice.

Any measures which are taken to reduce the external heat load on an individual will depend on the nature of that load. For example, a high radiant temperature may or may not be accompanied by a high air temperature and this will determine the nature of the protection required.

In the present investigation for B.I.S.R.A., a series of visits to steelworks has been made in order to define the various jobs where heat stress is regarded as excessive. It was not possible to take any environmental measurements in this preliminary survey and only subjective impressions were collected. However these, together with discussions within the industry, have probably revealed most of the important situations. The source of heat was usually fairly obvious and its direction has been used to group the situations under two headings.

### *Group A—Omni-directional Radiation*

It frequently happens that a worker is completely, or almost completely, surrounded by hot surfaces. He is subjected to strong infra-red radiation, but whether the air is also hot is a matter which has to be determined. Under these conditions work may be possible for only half, or even less, of the total time spent on the job. Examples of this situation are:

Repair and rebricking of open-hearth furnaces
Repair of checkers beneath open-hearth furnaces
Cleaning out of slag pockets and flues
Relining of mixers and Bessemer converters
Cleaning and repair of soaking pits.

In most of these cases it is usually essential to complete the work in as short a time as possible. At the moment this can only be done by employing one or more relief teams. If some means of protection can be devised, not only should each man be able to remain at work for much longer, but an earlier start on the job should also be possible. A furnace or soaking pit will probably be cooling quite slowly before work normally starts, but if some means of protection are used, it should be possible to begin work a good deal earlier, although the temperature is not very much higher than normal.

### *Group B—Uni-directional Radiation*

The other type of situation which is very common in steelworks occurs when the man is subjected to radiation from one direction only. Usually this exposure is intermittent or mild, but sometimes the intensity of radiation or length of exposure is such that some protection is indicated. Severe uni-directional radiation has been observed in the following operations:

Deseaming of ingots, particularly when large and red-hot
Bricking of ingots at furnace doors before forging
Cleaning slag from the noses of Bessemer converters
Hand sheet rolling
Work close to forging presses
Driving soaking-pit cranes.

At the moment the various situations listed in both these groups are being surveyed to try and define the conditions in terms of air temperature, radiant temperature, humidity, and air movement. Once this has been done it will be possible to specify the type of protection required.

### Methods of Protection

There are several methods available for protecting workers from excessive heat, and the choice of the best one will depend partly on the nature of the heat load and partly on the work situation. These existing methods can also probably be much improved.

#### (i) *Radiant Heat Screening*

In many cases where the radiation is uni-directional it can be reflected by suitable screens covered with polished aluminium foil. This material has the property of reflecting 90–95% of the radiation falling on it, so that a screen placed between the heat source and the worker can reduce the heat stress considerably. Murrell[15] gives an example of the value of such screening: "The case of men working between two

billet furnaces may be cited. Before screens were installed men worked for only 7½ min in every 30 (4 men to do one man's job). After screens were installed (cost £35) one man worked for 30 min, and then did another light job of controlling for the other 30 min. The saving was thus 3 men per shift, or a saving of about £8000 in wages over 3 shifts." Not all instances may be expected to give as dramatic a result as this, but several of the situations in Group *B* could probably be improved by screens, provided that they did not get in the way or obscure vision. If this happens, the screening can be in the form of clothing (*see* (iii) below).

(ii) *Air Conditioning*

If the worker is in a confined space such as a rolling-mill pulpit or soaking-pit crane cab, conditions can be eased by supplying the space with cool air. This has been done with success in various new installations, but it is often difficult to adapt existing plant. Air conditioning does not protect the operator from radiant heat; this can only be done by screening the outside of the cabin. While this would be efficient in mill pulpits, it seems likely that polished screening on crane cabs would soon become covered with oil and corrosion. Once this happened the screens would lose their effectiveness, so that careful maintenance would be needed.

There is a good deal of evidence which shows that men exposed to high temperatures become less efficient at skilled tasks comparable with controlling a mill or crane. It would be of interest to know whether data for efficiency or accident rate show a seasonal variation. A crane cab which may be reasonably comfortable in the winter often becomes quite intolerable for a period of 8 h in hot weather.

(iii) *Protective Clothing*

So far in this paper any discussion of the effects of clothing on heat regulation has been omitted for reasons of simplicity. Under ordinary conditions clothing acts as an insulating layer between the skin and the environment. It has been shown that a nude man cannot maintain his body temperature at rest in a temperature of 20° C, but when clothed this can be done with no difficulty.

Under hot conditions ordinary clothing acts as a barrier to the evaporation of sweat, even when the clothing becomes saturated. Cooling takes place on the surface of the clothing and the heat so abstracted has to be transferred across the clothing and the air gap between the clothing and the skin. In addition, there is a time lag until the clothing becomes wet.

The usual clothing fabrics can give short-term protection against radiant heat, although almost all the incident radiation is absorbed. The heat is stored in the clothing and, owing to its poor conductivity, takes some minutes to pass through to the skin.

For any long-term exposure to radiation, the principle of reflective screening must be applied to the clothing, and an excellent review of the possibilities has already appeared.[16] The most effective material has an outer layer of aluminium foil and will reflect, when new, over 90% of the radiation. One of the problems with this material is to obtain a durable aluminium layer that will stand up to use in a steelworks. For use in the Group *B* uni-directional situations, however, it appears to have been used with some success in steelworks in Germany and in aluminium works in Sweden.

One difficulty with this type of clothing is that the metal layer forms a barrier to water vapour or liquid sweat, so that metabolic heat production cannot be dissipated. If the garment is in the form of an apron, sufficient ventilation presumably takes place at the back, but information on this point is lacking.

The only effective protection against omni-directional radiation of Group *A* is a complete suit of the reflecting material, and this presents a serious problem in getting rid of heat produced in the body. The only means of doing this is to supply a stream of dry, and preferably cool, air beneath the suit. This method has already been used successfully to cool the crews in high-speed aircraft. The development of such a suit for use in the industry will need much more work, and a lengthy discussion at this stage seems inappropriate.

## CONCLUSION

There seems to be no theoretical reason why steelworkers should not be provided with a large measure of protection against excessive heat in the industry. This should lead to improved efficiency, with savings in time and manpower. Practical steps to try and accomplish this are now being taken.

## References


1. H. M. VERNON: " Fatigue and efficiency in the iron and steel industry," Report of the Industrial Fatigue Research Board No. 5: 1920, London, H.M.S.O.
2. H. M. VERNON: " The influence of hours of work and of ventilation on output in tinplate manufacture," Report of the Industrial Fatigue Research Board No. 1: 1919, London, H.M.S.O.
3. H. M. VERNON, T. BEDFORD, and C. G. WARNER: " The relation of atmospheric conditions to the working capacity and the accident rate of coal miners," Report of the Industrial Fatigue Research Board No. 39: 1927, London, H.M.S.O.
4. E. FARMER, R. ST. C. BROOKE, and E. G. CHAMBERS: " A comparison of different shift systems in the glass trade," Report of the Industrial Fatigue Research Board No. 24: 1923, London, H.M.S.O.
5. D. TURNER: *British Journal of Industrial Medicine*, 1957, vol. 14, p. 177.
6. C. BLAGDEN: *Phil. Trans. Roy. Soc.*, 1775, vol. 65, p. 484.
7. C.-E. A. WINSLOW, L. P. HARRINGTON, and A. P. GAGGE: *American Journal of Physiology*, 1937, vol. 120, p. 288.
8. R. F. HELLON *et al.*: *Journal of Physiology*, 1956, vol. 132, p. 559.
9. S. ROBINSON *et al.*: *American Journal of Physiology*, 1943, vol. 140, p. 168.
10. W. BEAN and L. W. EICHNA: *Federation Proceedings*, 1943, vol. 2, p. 144.
11. R. F. HELLON, A. R. LIND, and J. S. WEINER: *Journal of Physiology*, 1956, vol. 133, p. 118.
12. R. F. HELLON and A. R. LIND: *Ibid.*, p. 132.
13. R. F. HELLON and A. R. LIND: *Ibid.*, 1958, vol. 141, p. 262.
14. I. M. RICHARDSON: *British Journal of Industrial Medicine*, 1953, vol. 10, p. 269.
15. K. F. H. MURRELL: *Engineering*, 1957, vol. 184, p. 344.
16. I. M. SLADE: *Research*, 1955, vol. 8, p. 178.

# Devices and Developments in Engineering Psychology

*By C. B. Gibbs*

SYNOPSIS

**After a brief introduction to the history of engineering psychology, the paper deals with visual indicators and signals, and gives examples of redesigned manual indicators. This is followed by a general discussion of the psychological basis of the design of manual controls and of the practical implications of the psychological data. 1614**

ANY SHORT PAPER on engineering psychology can only serve as an introduction to the more extensive introductions to a literature which is now voluminous. The work has developed and expanded with great rapidity, particularly in the U.S.A., since the first large-scale studies of man–machine relationships were pioneered at Cambridge in World War II.

The broad aims of the studies are to obtain data concerning the human limitations and capacities that are important in manipulating tools or controlling machines. The purpose is to enable engineers to design machines that are easy and safe to use, with maximum operating efficiency, and a minimum of special selection and training for operators.

The methods used are to test a large sample of representative human operators in a series of different conditions, and to record their effects on performance, and so determine the best conditions.

The work has received great impetus from the rapid advance in technical efficiency, since in many man–machine systems the chief source of error or inefficiency now lies in the limitations or shortcomings of the human operator. It has been shown repeatedly that these can be greatly reduced by attention to the anatomical, physiological, and psychological characteristics of the human operator.

The large-scale work is of comparatively recent date, but there is a great deal of older work which is still too little known and far too infrequently applied.

It was in 1795 that Maskelyne, then Head of the Greenwich Observatory, discharged an assistant for alleged carelessness in recording the transit time of stars. This recording required an accurate timed response, at the instant when a star passed the crosshairs of a telescope. The assistant's times differed by half a second from those of Maskelyne.

The dismissal caused some political stir at the time, and in 1803 Donders began what may well be the first experiments in engineering psychology, by investigating the phenomenon which is now known as the ' personal equation.' He showed that some people tend to respond before, and some respond after, the instant of coincidence between a moving object and a fixed index, and that people vary greatly in their consistency of response.

Quite recently in personal experience, a case was found where the efficiency of a new and very expensive machine hinged upon the accuracy of the operator's response. The old studies, and the old solutions of the operators' difficulties, will probably find some useful applications in an important modern problem.

It is still worth recalling the work of Burnham, who in 1892 found that printed characters should be 1·5 mm high at the average distance of 14 in. in good illumination, to obtain the most rapid rates of reading with a minimum of errors.

Applications of such findings and methods to machine design have been comparatively few, although it follows immediately from Burnham's results that there is an optimum size for instrument figures and dials, when viewed in uniform illumination from a substantially constant distance.

### Visual Indicators and Signals

A great deal of information is now available on how to design visual indicators and instruments, so that information is conveyed quickly and clearly to the brain. Many experiments have been carried out to compare the relative efficiency of different kinds of indicators such as counters, dials, quadrants, and linear scales in different operating conditions. Different shapes, sizes, and proportions of dial figures have been compared, and the effects of contrast and illumination upon working efficiency have been widely studied. The literature dealing with visual limits and efficiency is now very extensive but there is a good introduction to the work by Paul Fitts in Steven's " Handbook of Experimental Psychology."

The studies described by Fitts are fairly general with a wide range of applications, but it is also useful to describe some specific applications of the data and the methods, which have obvious practical importance.

Figure 1 shows a familiar type of indicator, the circular micrometer indicator on a popular commercial lathe. The visual characteristics are extremely poor, with low contrast between the figures and their background, a bright reflecting surface.

There is a further operational difficulty if a large change of setting is required, say for turning two shoulders on a shaft, or in typical milling or boring operations. The conventional indicator is usually subdivided into thousandths of an inch, and a complete revolution moves the tool or the work by the pitch of the lead screw, say ½ in. A complete revolution may start at zero and end at zero on the indicator with nothing to show that the movement has been made. This leads to difficulties when large yet accurate settings have to be made by using the conventional indicators. It is necessary to convert the linear distance to the number of complete revolutions and fractions of a turn. Setting therefore involves some arithmetical calculation, and counting and remembering the number of turns which have been made. Experiments have shown that an appreciable number of errors occur in these processes.

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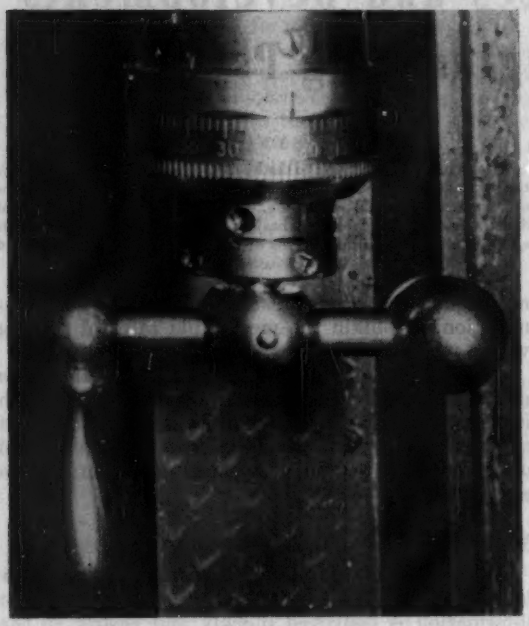

Fig. 1—Circular micrometer indicator on a lathe

An alternative device is shown in Figs. 2 and 3. The visual characteristics of this new indicator are greatly superior to those shown in Fig. 1. The size and contrast of the numerals make them far more easily seen, and their shapes and proportions were arrived at by experiments which aimed at maximum legibility and the least possible confusion between numerals of similar shape: e.g. 3 and 5; 6, 8 and 9.

The indicator can be arranged to give direct readings over a distance of several feet, with micrometer accuracy in the subdivisions. This is achieved by combining a quick-action counter mechanism with a rotating dial. The model shown in Fig. 2 is read horizontally. The number of inches are shown under the first counter window, tenths of an inch under the next, followed by hundredths and thousandths, which are engraved on the circular scale and read under the horizontal line on the window.

The new indicator can therefore deal with large distances with great accuracy, combining the characteristic of a tape measure and a micrometer. It is in effect a cheap yet accurate built-in micrometer, and experiments have shown that direct reading gives a substantial reduction in the training time of operators. Tests on typical turning and milling operations show that setting times and errors were substantially reduced, the savings depending on the type of operation.

There is little doubt that these and similar principles could be usefully applied to a wide range of measuring devices in many industries.

There are many different kinds of signal in common use which are intended to convey information rapidly yet accurately to the brain, but often achieve little success. The turning signals of cars are a case of considerable importance, since the wide range of different signals in different positions which are now permitted on cars undoubtedly adds considerably to the uncertainty and risk of driving on our congested and dangerous roads.

Experiments were carried out some years ago to compare the relative efficiency of the moving trafficator type, and the type of signal using a flash for turning and a steady-burning light for braking. The criteria used in the tests were relative visibility, the number of mistaken interpretations, and the time taken to make a suitable response to the signals. The flashing signals proved to be slightly better for visibility in some lighting conditions, but greatly inferior in respect to mistakes and the time taken to respond. It is difficult to understand why the flashing signals were made legal soon after the issue of the report, but the episode serves to illustrate the current apathy and indifference to scientific work on the limitations and capacities of human beings.

So far reference has been made only to single visual indicators. Although an array or panel of indicators is not a particularly recent development, it is obvious that the increasing amount of automatic and semi-automatic control of industrial processes will pose display problems of greater complexity.

Such a display must be thought of as a whole, representing the changing state of an entire system. Broadly this representation can be either abstract or functional. The former will be a compact, probably symmetrical panel of indicators. The latter, using more space, will attempt to arrange the indicators logically in relation to the actual plant.

The relative advantages of these two methods will naturally depend partly on circumstances, but certain things are clear. The functional layout is much more likely to keep the operator well in the total picture, since the relationship between indicators is given. This is usually a plus point. But the understanding of such relationships requires a higher grade of operative. A man capable of moving a lever whenever a pointer reaches a red line may not be able to follow the windings of a functional wall diagram and make a correct decision. In particular, when a plant is modified, leading to a reorganization of work, older workers may find the responsibility of keeping in touch with a functional display too much.

Both of these layouts will pose many problems in engineering psychology. One of special concern is when to provide a visual and when an auditory warn-

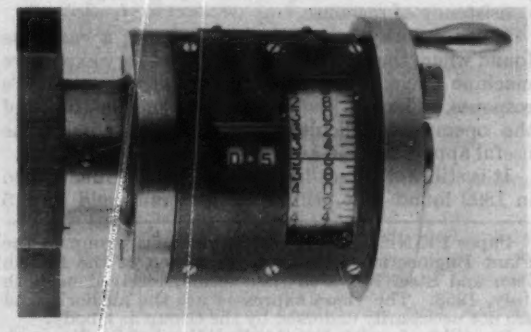

Fig. 2—New indicator for direct reading horizontally

ing signal. There is little doubt that in isolation a sound, and particularly an intermittent sound, is more attention-compelling than most visual indicators. But a sound will not readily give fine grades of meaning. Furthermore, the nature of the other likely sounds (continuous, frequent, and occasional) must be carefully considered, so as to avoid masking and confusion. In this context one can say confidently that the available range of auditory warning signals has been grossly underexploited in systems design.

One of the characteristics of this kind of display is that, although it continuously provides a great deal of information from a multitude of indicators, only occasionally is the operator called on to do something. The task of the operator is to detect malfunction in the system. In fact he has apparently very little to do. It has been clearly established experimentally that this kind of situation, far from providing the operator with an easy task, is psychologically difficult to cope with. The less often a signal for action occurs, the less likely is it to be noticed when it does occur. The problem of maintaining the vigilance of the operator can usually be met by providing him with a good deal of ancillary work. This must be such that it keeps him in contact with the display, but not in an obviously useless manner. Where no such other work is possible, spells of work of no more than half-an-hour are probably optimum. Two hours should be regarded as maximum.

### Design of Manual Controls

Many different forms of control levers, handwheels, and pedals can be used to regulate the output of a machine and can be arranged in different positions and operational planes, so that the operator's movements, and the muscle groups employed, may vary widely within the practicable limits of controller design. These varying conditions can be evaluated in terms of operator efficiency; experiments have been carried out, and data are available, to define the tolerance limits and optimum conditions for many of the controls in common use. The criterion of efficiency generally adopted has been the accuracy of discrete point-to-point movements, or continuous tracking movements in following a moving index, but other studies have investigated human force and power limits and the factors affecting fatigue. The available data must therefore be interpreted with the experimental criterion in mind, since the most accurate tracking control is certainly not the best type for displacing large weights at maximum speed.

The problem is complicated by the many different possible relationships between a unit movement of the control lever and the corresponding change in machine output. For example, the control characteristics of a lathe, where a unit control movement of the handwheel instantaneously alters the position of the tool, differ from those of a motor car, where a unit movement of the accelerator pedal alters vehicle speed, although an appreciable time must elapse before a new steady speed is reached. These control systems would be defined as 'instantaneous positional' and 'lagging velocity' respectively, and there are many different such relationships in modern machines. The particular time/space relationship may greatly affect

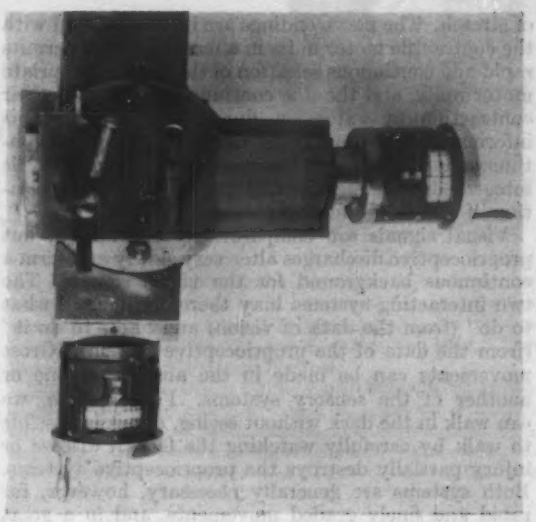

**Fig. 3—New indicator for direct reading vertically and horizontally**

learning time, and the ultimate efficiency of the man–machine system, after the operator is fully trained.

When skilled movements are made in response to a visual signal, many variables are introduced, and the action and interaction of different senses must be considered before any general principles of design can be established. The eye often acts as an 'error pick-up,' when, for instance, instruments are read and the extent, direction, and speed of the control movement that is required to correct any error in machine output, or to effect any desired change in environment, is observed. Before effective movements can be originated by the higher motor centres in the brain, continuous knowledge of limb states is necessary, so that the most appropriate limbs and neuromuscular units for a given purpose can be selected from those available.

A limb movement can be considered as the moving of a mass radially about a universal joint, by means of elastic contractile tissues connected to opposite sides of the limb. One set of motor units must be contracted while the other lengthens in exact synchrony, and compensatory adjustment may be required in other limbs not directly involved in the movement. Experience has shown that movements may be made at high speed, and with a fair degree of precision, in conditions where vision alone cannot regulate the complex internal muscular adjustments; the proprioceptive nerve-endings in muscles, tendons, and joints are then used for control purposes.

### Proprioceptors

The proprioceptors provide information about internal states and relationships such as limb positions and movements. They have electro-mechanical characteristics which are very similar to those of strain gauges, their electrical discharge being continuous, and the frequencies of discharge varying according to the tension on the muscle and its rate

of stretch. The nerve endings are interconnected with the contractile motor units in a manner which permits rapid and continuous selection of the most appropriate motor units, and the fine continuous grading of their contraction or extension during movement. This information, dealing with internal states, is continuously transmitted to the brain, where it is integrated with the visual data, to permit organization of the most effective voluntary action.

Visual signals are comparatively short-lived, but proprioceptive discharges alter very slowly and form a continuous background for the visual signals. The two interacting systems may therefore define 'what to do' (from the data of vision) and 'how to do it' (from the data of the proprioceptive system). Gross movements can be made in the absence of one or another of the sensory systems. For example, we can walk in the dark without seeing, and it is possible to walk by carefully watching the feet, if disease or injury partially destroys the proprioceptive systems. Both systems are generally necessary, however, for rapid and finely graded movements, and in a great many machines where the operator's performance is unnecessarily poor the correct balance between the senses may not have been achieved, or working conditions may not permit the senses to operate at their maximum efficiency.

In visuo-motor skills, two main sensory streams of information are transmitted to the brain, where they must be integrated and analysed. There is evidence to suggest that the brain, like other selecting and integrating devices, cannot exceed a certain working rate, and, apparently, the human operator can deal only with an average rate of five or six 'bits'* of information per second in certain conditions.

The time required for analysis or selection is the main component in the reaction time, which is the delay which occurs between the onset of a visual signal and the release of the appropriate muscular response. The time increases as a logarithmic function of the number of separate 'choices,' or different alternative movements, which the operator must hold in readiness awaiting the visual signal. Thus, if only one light can shine, and this is always the signal to press only one key, the operator will take about 0·2 s to react; but if a red light and a blue light are equally likely to shine, and to signal respectively for either a left-hand or right-hand key, reaction time increases to more than 0·3 s, with corresponding logarithmic increases for higher levels of choice.

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Combined controls, however, may often tend to improve the operator's efficiency, and are therefore preferable when a machine can be designed to use 'combined' as effectively as 'divided' controls. Machine characteristics can be altered, whereas human characteristics are relatively fixed, and are frequently the main source of errors. It is clear, therefore, that machines should be designed initially to suit the man, rather than attempting by selection and training procedures to fit the man into the machine.

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The "Iron and Steel Dictionary," ("Stahleisen Wörterbuch") which contains over 7000 terms, consists of 272 pages; it is of a handy pocket size and is strongly bound in imitation leather. The price from Germany is D.M. 12.50; copies may also be obtained through booksellers in the U.K., or from the distributing agents, H. K. Lewis and Co., Ltd., 136 Gower Street, London, W.C.1. Copies are **not** obtainable from the Institute.

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University of London; he is to carry out research for a higher degree in the electro-metallurgy department at Battersea College of Technology.

Mr. **M. C. Lloyd,** M.B.E., has been appointed a Director of Lloyds (Burton) Ltd.

Mr. **H. D. Morgan** has been appointed Chief Electrical Engineer of the Steel Division of the Steel Company of Wales Ltd.

Mr. **H. Morley** has succeeded Mr. J. D. Joy as General Works Manager of Samuel Fox and Co., Ltd.

Mr. **J. F. Perry** has retired from executive duties with the Metropolitan-Vickers Electrical Export Co., Ltd.

Mr. **I. S. Scott-Maxwell** has returned to full-time duties as Assistant Manager (Engineering and Development) of the Steel Division of The Steel Company of Wales Ltd.

Mr. **C. M. Slocombe** has been appointed Director of Engineering at Samuel Fox and Co., Ltd.

Mr. **R. Wilcock,** Works Metallurgist at Samuel Fox and Co., Ltd., is now responsible to Mr. R. D. Pollard, Chief Metallurgist, for all aspects of the company's internal activities in the metallurgical field.

Mr. **R. Whittaker** has rejoined Samuel Fox and Co., Ltd., as Process Metallurgist.

### Obituary

Mr. **Axel Axelson Johnson,** O.B.E. (*elected* 1906), of Stockholm, on 3rd August, 1958.

Mr. **Patrick O'Sullivan** (*elected* 1940), of Ilford, on 26th April, 1958.

Mr. **Samuel Thomson** (*Vice-President*; *elected* 1937), of Motherwell, on 7th September, 1958.

## AFFILIATED LOCAL SOCIETIES

### Staffordshire Annual Competition, 1958

Associates and Members of the Staffordshire Iron and Steel Institute below the age of 28 are invited to compete in the Institute's Annual Competition, for a paper of a practical nature of 2500–3000 words. The subject of the paper, which must be an original contribution, may be chosen from the following: ironmaking, steel manufacture, foundry work, hot and cold working of steel, fuels, refractories, engineering. The closing date for submission of papers is 31st December, 1958; forms of application may be obtained from G. Riley, Stewarts and Lloyds Ltd., Bilston Iron and Steel Works, Bilston, Staffs.

## IRON AND STEEL ENGINEERS GROUP

### Meeting on Cranes

The Thirty-Seventh Meeting of the Iron and Steel Engineers Group is being held in Chester from **14th to 16th October.** The meeting will open with a discussion during the afternoon of 14th October based on the following papers (the dates in parentheses refer to publication in the *Journal*):

"Crane Safety in the Iron and Steel Industry": A report of a Sub-Committee of the Accident Prevention Committee of The British Iron and Steel Federation.

"The Ergonomic Aspects of the Design of Cranes," by R. G. Sell (*Oct.*, 1958)

"Ergonomic Investigations into the Design of Motor Controllers," by A. Box and R. G. Sell (*Oct.*, 1958)

"Devices and Developments in Engineering Psychology," by C. B. Gibbs (*Oct.*, 1958)

"Human Temperature Regulation and the Steel Industry," by R. F. Hellon (*Oct.*, 1958)

On the following day, there will be an all-day visit to the Irlam Works of the Lancashire Steel Manufacturing Co., Ltd., followed by a dinner in Chester by invitation of the Company.

The meeting will end on the morning of Thursday, 16th October, after the presentation and discussion of the following papers:

"Structural Design of Steelworks Electric Overhead Cranes" by D. Buchanan and R. G. Tyler (*April*, 1958)

"The Plain-frame Method of Analysis for Lattice Girders" by R. G. Tyler (*Oct.*, 1958)

Circular notices about the Meeting have been sent out to all members. Copies of the Crane Safety Report will be sent to all those attending.

## BRITISH NUCLEAR ENERGY CONFERENCE

### New Member Society

The Joint Panel on Nuclear Marine Propulsion was admitted to membership of the B.N.E.C. on 16th July, bringing the total of constituent societies to nine. The Joint Panel was set up in 1956 by The Institution of Marine Engineers, The Institution of Naval Architects, The Institution of Engineers and Shipbuilders in Scotland, and The North-East Coast Institution of Engineers and Shipbuilders.

### Lecture Symposium on Geneva Conference

Over 2000 papers were presented at the Second International Conference on the Peaceful Uses of Atomic Energy, held in Geneva on 1st–13th September. The B.N.E.C. is organizing a one-day lecture symposium on 12th March, 1959, at which leading experts will attempt to highlight the most important aspects of the new information presented at Geneva; for this purpose, the papers will be divided into six or seven groups. The lectures will be printed in the April, 1959, issue of the *Journal of the B.N.E.C.*

### Symposium on Nuclear Fuel Cycles

As already announced, The Institute of Physics is holding a symposium on nuclear fuel cycles under the auspices of the B.N.E.C. on 22nd and 23rd January, 1959. Application forms may be obtained from the Secretary, 47 Belgrave Square, London, S.W.1.

## EDUCATION

### Ternary Systems in Metallurgy

A course of eight tutorials on "Ternary Systems in Metallurgy" is being held at the Northampton College of Advanced Technology, St. John Street, London, E.C.1, on Thursday evenings at 6.30 p.m., starting on 23rd October. The fee for the course, which will be conducted by Mr. F. B. Elliott, is two guineas; the syllabus includes the construction of ternary models and diagrams and the intepretation of the cooling of typical ternary alloys.

### Postgraduate Courses at Birmingham

The Department of Metallurgy of the College of Technology, Gosta Green, Birmingham 4, is offering courses on the metallurgy of nuclear power materials and on spectrographic and chemico-physical techniques for metallic materials during the autumn term. The former course consists of ten lectures on Tuesday evenings, starting on 7th October; it is intended for technical staffs engaged on research and development on nuclear reactors, and for students preparing for advanced examinations.

The course on analytical techniques consists of twelve lectures on Wednesday evenings, starting on 8th October. It is intended for metallurgists and chemists engaged in research and development work.

Full details of both courses and application forms may be obtained from the Department. The fee for each course is two guineas.

### Russian for Scientists

Russian language classes for scientists and technologists are being organized by the Holborn College of Law, Languages, and Commerce, Princetown Street, London, W.C.1. There will be two courses, one for beginners, and one for those with a working knowledge of Russian. Each course will consist of two evening lectures a week; the fee will be £1 12*s*. 0*d*. per year.

## CONTRIBUTORS TO THE JOURNAL

**A. W. Box,** B.A.—Electrical Engineering Section, Plant Engineering and Energy Division, B.I.S.R.A.

Arthur Box went to the University College of North Staffordshire in 1952 as a mature student, and obtained his degree in philosophy and politics in 1956. Before 1952 he had worked in various jobs, including four years as an engineering apprentice; he had also spent a year at Fircroft Adult Residential College, Birmingham. After graduating, Mr. Box spent a brief period as a trainee work-study engineer with the Mullard Radio Valve Co., Ltd., before joining B.I.S.R.A. in February, 1957.

**A. B. Collier**—Head of Creep and Mechanical Testing Department, Research Department, William Jessop and Sons, Ltd.

Mr. Collier was born at Eastbourne in 1928 and educated at Sheffield Technical School. He holds a Higher National Certificate in applied physics, and has been with Jessop's Research Department for twelve years. For the past five years he has been engaged on the testing and development of high-temperature alloys.

**E. E. Farmer**—Research Assistant, Mechanical Engineering Section, Plant Engineering and Energy Division, B.I.S.R.A. (*author of paper in September Journal*).

Edward Farmer was born in 1934 and educated at Collyer's School, Horsham. After military service in the Royal Artillery and R.E.M.E., he joined B.I.S.R.A. Mr. Farmer, who is a student member of the Institution of Mechanical Engineers, is studying mechanical engineering at Wandsworth Technical College and Battersea College of Technology.

**G. C. Olson,** B.A.SC.—Plant Superintendent, Atlas Steels Ltd., Welland, Ontario, Canada (*author of paper in September Journal*).

George C. Olson is a native of British Columbia, and obtained the degree of Bachelor of Applied Science at the University of British Columbia in 1941. On graduating, he joined Atlas Steels as a metallurgist; in 1943 he was made Melt Shop Metallurgist, and four years later became Atlas Plant Metallurgist, responsible for all mill process metallurgy. In 1949 he was appointed Melting Superintendent, and he took up his present position in 1955. As such, Mr. Olson is responsible for all aspects of special steel production within the Company.

E. E. Farmer

G. C. Olson

**R. G. Sell,** B.SC., DIP.PSYCH.—Senior Scientific Officer, Electrical Engineering Section, Plant Engineering and Energy Division, B.I.S.R.A.

Reginald Sell was educated at Latymer Upper School and University College London, where he obtained a B.Sc. (Special) degree in psychology in 1953. Before joining B.I.S.R.A. in 1954 he was a management trainee with the Beldam Asbestos Co., Ltd. Mr. Sell, who obtained a postgraduate diploma in occupational psychology in 1956 after studying part-time at Birkbeck College, is in charge of B.I.S.R.A. research on ergonomics.

**C. F. West**—Assistant Head of Creep and Mechanical Testing Department, Research Department, William Jessop and Sons, Ltd.

Mr. West, who is 29 and was born in Sheffield, has been with his present organization for twelve years, for the last five of which he has been working on the development and testing of high-temperature alloys. He holds a Higher National Certificate in Mechanical Engineering, obtained in 1955 as a result of part-time study at the Sheffield College of Technology.

**H. N. Wilkinson,** B.SC.—Mechanical Engineering Section, Plant Engineering and Energy Division, B.I.S.R.A. (*author of paper in September Journal*).

Mr. Wilkinson obtained a B.Sc. degree in mechanical engineering at South-West Essex Technical College in 1950. He then joined the British (now Central) Electricity Authority as a graduate trainee, later becoming Junior Control Engineer at Barking Generating Station. Mr. Wilkinson joined B.I.S.R.A. in 1954 and has been engaged on investigations of mechanical handling problems.

A. W. Box

A. B. Collier

C. F. West

H. N. Wilkinson

## NEWS OF SCIENCE AND INDUSTRY

### Shell–B.I.S.F. Filmstrips

A series of filmstrips on "Lubrication in the Iron and Steel Industry" is being prepared for the Training Department of the British Iron and Steel Federation by Shell-Mex and B.P. Ltd. There will be five filmstrips in all, covering every aspect of lubrication and most types of equipment.

The first in the series—"Friction and Lubrication"—is already available. There are fifty frames in the strip, all in colour, which explain the theory behind the use of lubricants simply and vividly. The subjects covered are the nature of friction, the source and nature of lubricants, the refining and blending of lubricating oils and the manufacture of greases, the tests necessary in manufacture, and additives and the reasons for using them. An accompanying commentary is provided with the strips, which takes about 40 minutes to deliver.

Further information may be obtained from the Training Department of the Federation.

### Verein Deutscher Eisenhüttenleute

The Annual Meeting and Eisenhüttentag of the Verein Deutscher Eisenhüttenleute is being held in Düsseldorf on 6th and 7th November. There will be a reception for overseas visitors on the evening of 5th November.

### Electric Furnaces for B.R.

British Railways, Midland Region, have placed an order with Birlec Ltd., of Birmingham for two electric-arc melting furnaces. It is understood that this will be British Railways' first electric melting equipment.

The new furnaces will be installed in the British Railways' foundry at Crewe, and will produce 21 tons of high-quality steel per day. Each furnace has a nominal capacity of 3½ tons and an electrical rating of 2000kVA.

### Corrigendum

In the August, 1958, issue of the *Journal*, in the discussion on translator control, the remarks from the beginning of the second paragraph in the left-hand column on p. 352 ("Where the type of programmer adopted . . . ") to the end of the third paragraph in the left-hand column on p. 353 should have been attributed to Mr. **H. Law** (English Electric Co., Ltd., Stafford).

## DIARY

**29th Sept.–3rd Oct.**—25th International Foundry Congress—Brussels.

**7th–10th Oct.**—Institution of Structural Engineers—50th Anniversary Conference—London.

**9th Oct.**—Leeds Metallurgical Society—"Tool Steels," by K. Hill—Chemistry Wing, University of Leeds, 7.15 p.m.

**9th Oct.**—Liverpool Metallurgical Society—Presidential Address: "Alternative Methods of Iron and Steel Production," by Dr. C. Bodsworth—Department of Metallurgy, University of Liverpool, 7 p.m.

**15th Oct.**—Swansea and District Metallurgical Society—Presidential Address, by Dr. R. Higgins, O.B.E.—Central Library, Swansea, 6.30 p.m.

**20th–25th Oct.**—Société Française de Métallurgie—Journées Métallurgiques d'Automne—Paris.

**24th Oct.**—Newport and District Metallurgical Society—Silver Jubilee Dinner—King's Head Hotel, Newport, Mon.

**25th–31st Oct.**—American Society for Metals—National Metal Congress and Exposition—Cleveland, Ohio, U.S.A.

**29th Oct.**—Liverpool Metallurgical Society—Visit to John Summers and Sons Ltd.

**4th Nov.**—Sheffield Metallurgical Association, Sheffield Society of Engineers and Metallurgists, and The Iron and Steel Institute—"Furnace Design and Steelmaking Techniques," by C. Holden—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

**6th Nov.**—Leeds Metallurgical Society—"Aluminium Bronzes," by C. V. Wilson—Chemistry Wing, University of Leeds, 7.15 p.m.

**6th–7th Nov.**—Verein Deutscher Eisenhüttenleute—Annual Meeting—Düsseldorf, Germany.

## BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 80 of the September, 1958, issue of the Journal:

688. Khokhlov, D. G., *et al.*: "Experiences with Automatic Speed Control of Sintering Machines for ensuring the Completion of the Process." *Stal*, 1957, June, p. 481. (£6)

689. Fil, N. S., and I. S. Lemberikman: "Conveyor Charging of Blast-furnace Skips." *Stal*, 1957, June, p. 493. (£2 10*s*.)

735. Ganich, A. A., *et al.*: "Automatic Apportioning and Weighing of Blast-furnace Burdens and Conveyor Belt Loading of Skips." *Stal*, 1957, June, p. 496. (£3 10*s*. 0*d*.)

769. Nürnberg, W.: "Results of Testing the Mode of Operation of Blooming Mills. Part III—Stressing and Mode of Operation of the Electric Drive." *Stahl u. Eisen*, 1957, Oct. 31st, pp. 1593–1607. (£8)

785. Moneybon, M., and D. Seferian: "A Contribution to the Study of the Influence of Hydrogen on the Impact Properties of Metals laid down by the Electric Arc with Coated Electrodes." *Soud. Tec. Conn.*, 1957, Sept.–Oct., pp. 277–289. (£3 10*s*. 0*d*.)

786. The International Institute of Welding—Committee X: Residual Stresses and the Relaxation of Stress: "Stress Relief of Alloy Steels," ed. by Soete and Tummers. *Soud. Tec. Conn.*, 1957, Sept.–Oct., pp. 333–337. (£2 10*s*. 0*d*.)

815. Hennion, J.: "Arc and Gas Butt Welding of Ferritic Steel Boiler Tubes." *Soud. Tec. Conn.*, 1957, Sept.–Oct., pp. 323–332. (£5)

877. Bukowiecki, A.: "Metal Corrosion caused by Hygroscopic Solids." *Schweiz. Arch. angew. Wiss. u. Techn.*, 1957, No. 4, pp. 97–104. (£4)

936. Novik, L. M. "Improvement of the Quality of Steel by Vacuum Treatment of the Liquid Metal and Casting in a Protective Atmosphere." Chapter III of "The Use of Vacuum in Steel Melting Processes," pp. 34–80. State Scientific Institute for Heavy and Light Metallurgy, 1957, Moscow. (£9 10*s*. 0*d*.)

959. Beaujard, L., and V. Husarek: "Some New Equipment for Continuous Non-destructive Control of Metals." *Métaux*, 1957, Dec., pp. 459–468. (£4 10*s*. 0*d*.)

961. Wever, F., *et al.*: "Spectrographic Investigation of the Converter Flame during the Basic Bessemer Process." *Stahl u. Eisen*, 1956, Aug. 9th, pp. 1032–1040. (£4 10*s*. 0*d*.)

976. Fischer, W. A., and M. Wahlster: "Experimental Basic Converter with Continuous Bath Temperature Measurement and End Point Determination." *Stahl u. Eisen*, 1958, May 15th, pp. 646–654. (£6 5*s*. 0*d*.)

992. Stenger, W., and O. Dahlke: "The New Hot Strip Mill of Borsig A.G." *Stahl u. Eisen*, 1958, June 12th, pp. 812–820. (£5 5*s*. 0*d*)

995. Roos, A.: "The Reactivity of Iron Oxides." *Chimie et Industrie*, 1957, Sept., pp. 206–213. (£4)

1001. Mevis, N.: "Operating Costs of the Internal Transport Services of Iron and Steel Works." International Transport Conference, June 1958, Liège. (£3 10*s*. 0*d*.)

1014–1018. *Papers on Continuous Casting of Steel, presented at the Special Meeting in Charleroi, 1958, and abstracted in J.I.S.I., 1958, June They are published in an abridged form in J.I.S.I., this month but are meanwhile being included in full in the Translation Service, at reduced prices.*

1014. Zaeytydt, J.: "Continuous Casting at the Centre National de Recherches Métallurgiques, Section du Hainaut à Charleroi." (£2)

1015. Siegfried, W.: "Control of Flow of Liquid Metals during Continuous Casting." (£2 10*s*. 0*d*.)

1016. Speith, G., and K. Bungeroth: "Experience with the Continuous Casting of Steel in Western Germany." (£1 10*s*. 0*d*.)

1017. Krainer, H., and B. Tarman: "New Experience in the Continuous Casting of Steel." (£2 10*s*. 0*d*.)

1018. Thomas, P.: "The Continuous Casting of Steel in France in 1958." (£1)

1023. Fechter, F.: "Pusher-type Furnaces with Full Automatic Control and Ceramic Skid Rails." *Stahl u. Eisen*, 1958, Mar. 6th, pp. 299–303. (£3)

1028. Koch, W., and H. Sundermann: "Magnetic Separation of Electrolytically Isolated Structural Constituents from Metallic Materials." *Arch. Eisenhüttenwesen*, 1958, Apr., pp. 219–224. (£4 10*s*. 0*d*.)

1030. Hansen, M.: "The Use of Models for studying Flow in Open-hearth Furnace Checkers." *Stahl u. Eisen*, 1958, June 12th, pp. 804–812. (£5)

1032. Zakharikov, N. A.: "Effect of Non-uniformity of Temperature in Gas Flow on Heat Exchange in Furnaces." *Stal*, 1956, Oct., pp. 927–933. (£5 5*s* 0*d*.)

1048. Klyachko, Yu, A., and M. M. Shapiro: "The Determination of the Titanium Nitride in Steel." *Zavods. Lab.*, 1957, vol. 23, No. 2, pp. 140–143. (£2 10*s*. 0*d*.)

*A classified list of translations (covering the period July/August) has been sent to all who receive our fortnightly lists of new translations, and is available to others, gratis, on request.*

# ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

## Iron and Steel Manufacture and Related Subjects

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*Abstracts, the reference to which is marked with an asterisk are to be made available as translations.

### MINERAL RESOURCES

**Iron Ores in Poland.** R. Osika. (*Min. Mag.*, 1958, **98**, May, 282–283; from *Zycie Warszawy*, 1958, Feb. 22). New reserves at Bialaczow, Przytyk, Niemica and Leczyca are briefly reported with estimates. It is expected that output will be raised to $10^6$ t. in 10–12 years.

**Ilmenite and Other Black-Sand Minerals in the Gold Fork Placer Deposit, Valley Co., Idaho.** R. H. Storch. (*U.S. Bur. Mines, Rept. Invest.*, 1958, No. 5395, May, pp. 15). **Ilmenite and Other Black-Sand Minerals in the Deadwood Placer Deposit, Valley Co., Idaho.** R. H. Storch. (*U.S. Bur. Mines, Rept. Invest.*, 1958, No. 5396, May, pp. 15).

**Iron Ore Reserves in Mexico.** S. Villamar. (73–76). Political aspects of development are discussed. **The Problem of Manganese Ore.** P. G. Quintanilla. (77–83). The critical position of Mexican Mn reserves and the steps necessary to rectify it are discussed.

### ORES—MINING AND TREATMENT

**Iron Ore Mining at Steep Rock.** G. E. Pearse. (*Mine Quarry Eng.*, 1958, **24**, July, 284–291).

**Recovery of High-Grade Iron Ore at Copper Cliff, Ontario.** P. Queneau, E. H. Bracken and D. Kelly. (*Found. Trade J.*, 1958, **104**, May 15, 579–580). Flotation and roasting of a sulphide ore are outlined.

**Handling Iron Ore in Bulk.** H. G. Jarman. (*Min. Mag.*, 1958, **98**, June, 329–332). Conveyor systems at the U.S. steelworks along the Great Lakes serving 7 blast furnaces, 34 O.H. furnaces and 7 coke-oven batteries are described.

**Experience in Luxembourg of Ore Preparation.** J. Paquet. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 4). Eight year's experience at the Arbed-Belval works with the sintering of crushed ore in a rotary kiln is described. A full series of trials of the effect of more intensive crushing and the effect of increase of sinter input ratio with 50% and with 65% of sinter in the burden are reported.

**Iron Ore Preparation in the U.S.S.R.** I. P. Bardin. (*Iron Coal Trades Rev.*, 1958, **176**, May 16, 1153–1154). The installations of sintering plants are named with some statistics.

**Production of Pellets from Ore Concentrates and Fine Ores.** F. M. Bazanov, F. F. Kolesanov, I. L. Malkin and S. I. Sharov. (*Stal'*, 1958, (4), 289–294). Pelletized ore is roasted on the grating of a sintering machine. Magnetite oxidises to haematite and recrystallizes and slag bonds are formed. Gas–air mixture with excess air is used and as the bed has a high permeability it can be as much as 24 in. thick. A strand with suction area of 50 $m^2$ with a 28 min. roasting period produces 2000 tons/24 h.—R. S.

**Production of Self-Fluxing Sinter.** J. S. McMahan. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 373–375; 497–498). An account of a trial using self-fluxing sinter in the burden of a blast furnace at the Steel Co. of Canada is presented. Up to 20% dolomite was added to the sinter mix and the optimum value was 18%. The furnace output increased by 8½% and coke rate by 6½%. The sinter plant output increased when making self-fluxing sinter, though the sinter was more friable than normal sinter. Tests were also carried out using calcite fines. When 15% dolomite and 10% calcite fines were used the furnace output increased by 17% and the coke rate decreased by 23·5% over the practice with normal sinter.—B. G. B.

**Experience with Sponge Iron Production in Wiberg–Söderfors Furnaces.** H. Kihlander. (*Jernkont. Ann.*, 1958, **142**, (3), 93–104). A description of the furnace and its operation is given. The annual capacity is 30,000 t. Coke is used as fuel and hydrocarbon gases can be used to increase production and decrease fuel and power consumption. Sponge iron is suitable for electric steel furnaces, only limited amounts can be used in the acid O.H. furnace. The cost is comparable with that of desulphurized pig iron.

**Direct Production of Semi-Reducible Iron Sponge.** (*Stal'*, 1958, (4), 302). A brief account of work at the Urals Institute of Ferrous Metallurgy on the production of iron sponge for use in steel furnaces. Laboratory studies of temperature, gas volume and composition on the reduction of oxides are noted.

**Stability of Strongly Magnetic Iron Oxides in Roasted Ores.** P. A. Tatsienko. (*Stal'*, 1958, (4), 295–297). When oxidized in a current of air roasted Kerchensk ores and ores naturally alloyed with Cr and Ni form $\gamma$–$Fe_2O_3$. The less stable form is produced from Krivoi Rog ores. Roasting conditions are discussed for these ores.—R. S.

**The Oxidation Rates of Lump Copper–Iron Sulphides.** T. A. Henderson. (*Bull. I.M.M.*, 1958, **67**, June, 437–462). The progress of roasting at temperatures above 600° is investigated.

**The Oxidation of Ferrous Oxide in Air in the Range 600 – 1350° C.** J. Païdassi. (*Acta Met*, 1958, **6**, March, 219–221). [In French]. The relative thickness of the layers of $Fe_2O_3$ and $Fe_3O_4$ formed on FeO derived from the oxidation of Armco iron, is constant at 750°–1350° C and the same as that for layers formed during oxidation of iron. The rate of growth is parabolic.—A. D. H.

**Some Peculiarities in the Oxidation of Magnetite in Air at 400–1350° C.** J. Païdassi and J. Lopez. (*Acta Met.*, 1958, **6**, March, 221–223). [In French]. The interface between $Fe_3O_4$ and $Fe_2O_3$ is irregular in the range 400°–800° C and at $<$ 900° C nodules or needles of $Fe_2O_3$ form. These effects are discussed in relation to the stresses set up during its formation and the orientation of the grains of $Fe_2O_3$ first formed.—A. D. H.

**On the Oxygen Content of Wustite in Equilibrium with Various Gas Phases.** N. Å. Hovgard and P. N. Jensfelt. (*Jernkont. Ann.*, 1956, **140**, (7), 467–492). Experimental values were obtained modifying somewhat the calculated isotherms of Wiberg. The activity of O and Fe in wustite was also calculated.

### FUEL—PREPARATION PROPERTIES AND USES

**On the Theory of the Partition Curve and its Application to Coal Preparation or Mineral Dressing.** K. Aso. (*Mem. Fac. Eng. Kyushu Univ.*, 1937, **17**, Dec., 19–83). [In English].

**Second National Congress of the Iron and Steel Industry.** [Mexico] 1957. *The Coking Quality Coals of the Carboniferous District of Coahuila.* J. J. Gonzalez A. (5–8). A brief account of these deposits, their nature and working is given. Higher mining efficiency is recommended in order to conserve the supply.

**Comparison of Wet and Dry Coal Preparation Processes with Reference to the Preparation of Hungarian Coals and the Development of the Dry Process in Hungary.** K. Martiny.

(*Publications of the Hungarian Research Institute of Mining*, 1957, (1), 3–16).

**The Coking Coal Problem in South Africa.** (*Coke Gas*, 1958, **20**, May, 189–192, 196).

**The Operation and Function of the Reversing Monitor System for the Heating of Coke Oven Batteries.** P. Palumbo. (*Blast Furn. Steel Plant*, 1958, **46**, May, 484–488). The instrumentation installed at the 22 coke oven batteries at the Clairton Coke and Coal Chemical Works of U.S. Steel for monitoring the reversal of the air and gas on each battery is described in detail.—B. G. B.

## AIR POLLUTION AND SMOKE

**The Problem of Keeping the Atmosphere Free from Pollution, with Special Reference to Ironworks, and Particularly Steelworks Practice. I.** K. Guthmann. (*Radex-Rund.*, 1958, Jan., 3–30). This section deals with the general problem of air pollution by dust and gases and then studies the various aspects of contamination of the atmosphere by dust, waste gases and ashes. The special problem of silicosis in steelworks and foundries is discussed, and the article concludes with a description of waste gas cleaning plants, and an outline of the regulations governing air pollution in various countries. (90 ref.)

**Deposition of Dust Particles from Industrial Stacks.** G. T. Csanady. (*Aust. J. Appl. Sci.*, 1958, **9**, Mar., 1–8).

**Ash and Its Influence on Furnace and Boiler Operation.** (*Energie*, 1956, **8**, July 15, 260–264). Uses of ash are also discussed.

## TEMPERATURE MEASUREMENT AND CONTROL

**Automatic Temperature Regulation.** A. Liébaut. (*Mém. Soc. Ing. Civils France*, 1957, **110**, Nov-Dec., 531–553). A general survey is given of methods available for the automatic regulation of temperature, classified according to the method of regulation.—L. D. H

**Instrumentation for Iron and Steel.** B. O. Smith. (*Iron Coal Trades Rev.*, 1958, **176**, May 16, 1147–1152). O.H. roof temperature and furnace pressure measurements and the possibilities of using these for automatic control are discussed. Bessemer plant instrumentation, bath temperature, strip inspection and thickness measurement and tinplate inspection are also briefly reviewed. Maintenance and future outlook are also considered.

**Complex Automation Processes in Ferrous Metallurgy.** (*Stal'*, 1958, (6), 481–85). An editorial. Points about blast furnaces and their instrumentation, the advantages of full automation and the problems involved and further devices required are made. Control of O.H. plants is then discussed. Radiation pyrometers for roof temperatures are being replaced by more precise instruments and the temperature of combustion products is also being measured. The oil-fired furnaces at the Red October plant are completely programmed. Arc furnaces and converters have also been considerably instrumented, flame spectra and the whole range of noise are being studied.—B. S.

## REFRACTORY MATERIALS

**Automatic Techniques Aid Refractory Brick Production.** (*Ceramics*, 1958, **9**, June, 35–36). A general account of the production of magnesite bricks by the Steetley Co. is given.

**First National Congress of the Iron and Steel Industry [Mexico]. 1955. Limitations in the Use of Refractory Materials in the Iron and Steel Industry.** A. Garza jun. (3–8). The constituents, temperature limits and shortcomings of steelplant refractories are discussed. Points to consider when choosing refractories are listed. **The Importance of Collaboration between Consumers and Manufacturers of Refractories.** H. Fetter (9–10). Illustrations of how this helps the development and design of new products are given.

**Development in Mexico of Refractory Materials Used in the Steel Industry.** A. Garza. (*Second National Congress of the Iron and Steel Industry [Mexico]*, 1957, (9–14). Brief details are given of the range of refractories shortly to be available; raw materials for basic refractories are imported.

**Experiments on the Pressing of Refractories at High Temperatures.** V. Ya. Riskin and V. V. Goncharov. (*Ogneupory*, 1957, **22**, (4), 186–188). Chamotte, high-alumina, magnesite and chrome–magnesite refractories were pressed at 1300–1500° C and micrographic and phase analyses are reported. Bulk density, porosity and refractoriness under load of four materials are given. The value of the process is discussed.

**The Effect of Iron Spots in Silica Bricks in Coke Ovens on their Behaviour in Service.** E. Perez Blanco. (*Inst. Nac. Carbon Bol. Inf.*, 1958, **7**, Jan.-Feb. 21–26). It is concluded that little damage is done by the ferruginous zones and that carbon deposition is insignificant.

**Refractories for the New Steelmaking Processes.** J. H. Chesters. (*Refract. J.*, 1958, **34**, Apr., 145–167, 170, 174; discussion 175–179). A general review of the application of $O_2$ in the O.H. and the newer steelmaking processes with reference to the higher temperatures and gaseous atmospheres involved and the composition of refractories. (27 refs.).

**Developments in the Use of Refractories at the Abbey Melting Shop of the Steel Company of Wales Ltd.** G. M. Workman. (*Refract. J.*, 1958, **34**, May, 204–216, discussion 218–220, 222). Experience with 200-t furnaces is described. Roof construction, walls and ends are described and illustrated and modes of failure considered.

**Some Physico-Chemical Aspects of the Corrosion of Refractory Products. (Part 1).** G. van Gijn. (*Silicates Ind.*, 1958, **23**, Feb., 63–66). The influence of diffusion in the corrosion of refractory products, the effects of the heterogeneity of the material, its porosity and the existence of a temperature gradient are discussed, with reference to brick containing varying amounts of silica and alumina.—L. D. H.

**The Stabilisation of the Cubic Form of Zirconia.** J. Stocker, R. Collongues and M. Moser. (*Silicates Ind.*, 1958, **23**, Feb., 67–71). It is known that the cubic form of zirconia can be stabilised by CaO, MgO or the rare earths. The authors show that this list can be extended to a number of oxides of bivalent and trivalent metals.—L. D. H.

**Critical Study of a New Flow Device for Studying Silico–Alumina Materials.** L. Lecrivain. (*Silicates Ind.*, 1958, **23**, Feb., 81–89). Trials over a long period of the apparatus developed by the Société Française de Céramique for investigating the flow properties of refractories showed that the equipment was liable to errors. The causes of these errors are analysed, and remedies suggested.

**The Optical Properties and Structures of CaO, $2Al_2O_3$, and SrO, $2Al_2O_3$.** E. R. Boyko and L. G. Wisnyi. (*Acta Cryst.*, 1958, **11**, June 10, 444–445).

**The Determination of Reactive Magnesium Oxide in Caustic Burnt Magnesite.** H. Haas, F. Kahler and K. Reischl. (*Radex-Rund.*, 1958, Jan., 47–59). The method depends on alterations in pH value when small and constant additions of HCl. are made at 1 min. intervals to a standardized preparation of the sample, to which water has been added. The effects of probable impurities are discussed. The method is inapplicable to samples containing appreciable amounts of Mg $(OH)_2$.

**Effect of Refractory Materials of Steel Pouring Devices on the Content of Non-Metallic Inclusions in Steel.** E. S. Kalinnikov and A. M. Samarin. (*Conference of the Academy of Science, U.S.S.R. on the Peaceful Uses of Atomic Energy*, 1955, 3–27). Increase of $O_2$ in ball-bearing steel during tapping from an electric furnace was measured. The amount of inclusions derived from the ladle lining is related to refractory composition. High alumina bricks are recommended, the effect of the sprue being small. Tracer studies were also made.

## IRON AND STEEL, GENERAL

**State of the Spanish Iron and Steel Industry.** S. Felgueroso Nespral. (*Bol. Min. Indust.*, 1958, **37**, Jan., 7–12). The author discusses raw materials and national production, world markets and steel production in 1956, demands and distribution of steel production in Spain, expansion of the industry and the scrap problem.—P. S.

**The Vizcayan Steel Industry.** (*Dyna*, 1958, **32**, Jan.). [In Spanish]. **The Importance of the Medium Vizcayan Steel Industry.** (111–113). The problems of the manufacturing concerns, particularly the need for new machinery and imported raw materials are discussed. **Vizcayan Iron Ore** (115). Progressive impoverishment of the deposits is shown to demand new exploitation techniques. **Altos Hornos de Vizcaya S.A.** (128–131). Photographs and details of this Company's plant are given. New construction includes two blast furnaces, convertors and rolling mills. **Vizcaya and National Metallurgical Progress.** F. Igartua (137–138). Iron production in Vizcaya was 52·54% of national production in 1956; steel production was 48·15%. Similar proportions were expected in 1957 in spite of various difficulties.—P. S.

**The Steel Industry of Japan.** (*Publ. of Jap. Iron and Steel Fed.*, [1958], pp. 26). A general review with list of firms, statistics and sections on wages and conditions and safety.

**1957 Review of Iron and Steel Production and Techniques in Japan.** T. Yamaoka. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 4–9). [In Japanese].—K. E. J.

**Review of the Iron and Steel Industry of Mexico.** P. G. Quintanilla. (*Second Nat. Congress Iron and Steel Industry [Mexico]*, 1957, 351–359).

**Modern Iron and Steel Plants.** P. Rheinlander. (*Iron Coal Trades Rev.*, 1958, **176**, May 30, 1261–1267; from *Stahl und Eisen*, Jan. 9, 1958).

**Some Mechanical Equipment in the Heavy Industries of South Wales.** W. F. Cartwright and I. S. Scott-Maxwell. (*Proc. I.M.E., preprint*, 1958, June 18, pp. 16). Metallurgical topics are included (9–15). Ore discharge, steam-raising and by-product electricity, blowers, and a slabbing mill and cut-up lines and a rod mill are briefly noted, also tinplate annealing equipment.

**Report of Activities for the Years 1955 and 1956.** *I.R.S.I.D. Report. Series B.* No. 36, 1957, Dec., pp. 237). The organization and composition of I.R.S.I.D. is set out and the principal researches and publications of the various divisions are summarized. Ores, sintering, blast-furnace practice, direct processes, (51 ref.); steelmaking, use of oxygen, desulphuration with limestone, O.H. work, and ingot casting, (33 ref.); Combustion research in the laboratory and works; Rolling mills, cold and hot; Metallography, tests of strength and fatigue and the kinetics of transformations, non-destructive testing, tracer studies and microscopy; Physics, (33 refs.); Physical Chemistry, liquid alloys; equilibria, chemical and thermal and temperature control; Analysis, including gas analysis, and corrosion; Statistical Department studies and the work of allied bodies are all reviewed.

**Research: Foundation of Steel's Progress Today.** J. B. Austin. (*J. Franklin Inst.*, 1958, **265**, May, 385–394). A lecture. The research programme of U.S. Steel is outlined.

## BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

**Survey of Modern Blast-Furnace Techniques** T. P. Colclough. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 19). Thermal balances of furnaces with prepared and unprepared burdens are worked out. The smelting operation is divided into four zones for this purpose. Effects to be expected from self-fluxing sinter, higher pressures and temperatures and addition of steam and $O_2$ to the blast are considered.

**A Soviet Delegation's Observations on British Blast-Furnace Plants.** G. I. Adaryukov. (*Metallurg.*, 1957, (3), 45–48).

**A Problem of Blast-Furnace Operation.** A. Gonzalez Ballesteros. (*First National Congress of the Iron and Steel Industry, [Mexico]*, 1955, 171–174). In 1952 a hot spot and

subsequent break-out occurred, about 6 m below the charging bell, about 21 days after changing the furnace over to ferro-manganese production. Observations showed that this was caused by severe chemical attack as a result of the collection of fines at this point, and their high alkali content.

**Preparation of the Blast Furnace Burden: French Experience.** J. Astier. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 8). Work on Lorraine ores is described. Crushing plants have increased, but sinter plants are not so far advanced. A trial with 100% sinter in a furnace 5 m dia. at the hearth is described. The coke consumption was 708 kg/ton with a blast temperature of 675° C and a throat temperature of 261° C. Physical enrichment is then considered.

**On the Running of 1-Ton Experimental Blast Furnace.** K. Kanamori. (*Tokyo Univ. Rep. Inst. Ind. Sci.*, 1957, **6**, Sep., 284–352). [In Japanese]. The furnace of internal volume approx. ½ cu. m, was built to assist studies on the "special bessemerising" process in the hearth. It has a deep hearth, a 60° tuyere for experimentation and h.f. induction heating to compensate for heat losses. Four campaigns are described, during which a satisfactory hearth lining and operating conditions were determined. "Bessemerising" conditions achieved a temperature rise of 30° C/min, but sulphurization occurred and it is concluded that sulphur cannot easily be removed by a metal-slag surface reaction. Chromium could be eliminated from molten metal by "bessemerising" and cooling the bath, but at the expense of loss of C and gain in S.—K. E. J.

**Experience with Sinter Burden in Swedish Blast-Furnaces.** U. Notini. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, reprint*, pp. 6). Most Swedish furnaces use 100% sinter, many use self-fluxing sinter. The results are analysed and coke consumption and other advantages are noted. The height of the shaft might be reduced and a more uniform product obtained, but hanging of the charge and slips may become more frequent. The advantages of self-fluxing sinter are held to justify crushing and concentration even if the beneficiation is as low as 1–2% or even absent.

**Use of Oxygen, Moisture and High Top Pressure in Blast Furnace Operation.** J. M. Strassburger. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 16). Processes which have increased pig iron output per furnace up to 27·5% while reducing coke rate to 137 kg/t are described. Blast enrichment was found also to require increased humidity which widens the combustion zones of the tuyeres. Circulation temperature has also been raised by supplementary humidification. High top pressure as used at Great Lakes Steel Corp., also increases production. Accurate preparation of charge is emphasized.

**Relationship Between Coke Consumption and Productivity of the Blast Furnace and Sinter Basicity.** I. B. Strashnikov, A. G. Astakhov, G. B. Ksendzyk, N. V. Fedorovskii, and K. A. Shumilov. (*Stal'*, 1958, (5), 398–402). Coke consumption per t of iron using self-fluxing sinter is determined by the ore charge in relation to coke and is inversely proportional to sinter basicity. Complete exclusion of limestone gives the greatest saving of coke in the southern furnaces of the Ukraine. Combustion intensity depends on sinter size and increases with increase in the large fraction in the sinter. Productivity varies with ore charge per unit of coke (increasing with basicity) and intensity of combustion (decreasing with basicity). Screen analysis must be improved on account of the large proportion of fines in the sinter. The basic criterion of the quality of sinter must be the fraction over 1 in after the drum test.—R. S.

**Effect of the Location of the Zone of Combustion on the Working of the Blast Furnace.** B. S. Fialkov and V. K. Gruzinov. (*Stal'*, 1958, (6), 495–502). The location depends not only on temperature and blast consumption but also on the regions of intensive melting and distribution of charge at the top must be related to the location of combustion zones. The tuyere projection is associated with the conception of ellipsoids of disintegration and where these are correctly taken into account the effect of furnace profile on the descent of the burden is said to be negligible.—R. S.

**A Programme-Controlled Reduction Test for Blast-Furnace Burdens.** R. Linder. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 13). Ore reducibility is discussed and laboratory testing simulating furnace conditions are examined. The ore quality is referred to its composition, mechanical strength, reducibility and resistance to break-up during reduction. Reducibility is measured by extent of oxidation at 1000° C and an equation is developed and explained. Apparatus for carrying out the test is described. Tests on sinters show good agreement with blast furnace findings.

**[Complex Automation of the Blast Furnace Process].** A. D. Kutsenko. (*Stal'*, 1958, (5), 403). A brief note.—R. S.

**Blowing Reducing Gases into the Blast Furnace Hearth.** M. A. Shapovalov. (**Stal'*, 1958, (5), 385–390). Coke oven or natural gas together with oxygen enrichment is claimed to be the best method. Coke oven gas is made available by the growth of converter production. A saving in cost of 3% and of 65 kg coke for every 100 m³ of gas fed to the hearth per t. iron is claimed. The tuyere design is shown and interrelationships between many variables are worked out.—R. S.

**Stepping Up Blast Furnace Production by Varying the Composition of the Blast.** E. M. Lokshin and Yu. S. Borisov. (*Stal'*, 1958, (5), 391–397). Enrichment by fuel oil, natural gas, coke-oven or producer gas or the blowing of powdered coal directly into the furnace is effective. Coke consumption can be reduced by as much as 30–35 %with increase of productivity up to 45%. Steam and $CO_2$ do not appear promising. Preheating is useful just as extra heating of normal blast is useful. Methods of calculation for evaluating various kinds of "combined" blast are given.—R. S.

**Hanging in the Blast Furnace when Using Oxygen Enriched Blast.** S. K. Trekalo. (*Stal'*, 1958, (6), 489–495). Hard driving produced hanging when oxygen enrichment was introduced. This was successfully overcome.—R. S.

**A New Method of Feeding Steam into the Space Between the Bells of Blast Furnaces.** L. A. Lepikhin and L. Ya. Shparber. (*Stal'*, 1958, (6), 503). High top pressure and the use of hot sinter caused explosions if steam was not constantly fed into the space between the bells. Complete safety was not secured with 2 t/h of steam while wear of the packing of the bell rod was accelerated and material was ejected on opening the small bell. An automatic feeding system for the steam is described which overcomes these defects.

**Heat Resisting Blowpipes for Blast Furnaces.** N. S. Reizov, L. Ya Shparber and V. M. Zudin. (*Stal'*, 1958, (5), 397). A brief note on baffled heat-resisting pipes for high temperature blast (to 950° C) and high top pressure furnaces is given. Advantages are noted and construction and dimensions are indicated.

**Gary Works' Experiences with Quartzite Blow-Outs.** R. E. Turman and T. A. Young jun. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 391–395). The use of quartzite pebbles to fill the stack of a blast furnace immediately prior to blowing out is described. The results obtained on 3 furnaces at Gary Works, U.S. Steel Corporation are discussed.—B. G. B.

**Camera Checks Furnace Linings.** (*Steel*, 1958, **142**, June 2, 74). Photographs of banked blast furnaces at 200° F were taken by a method briefly described.

**Inside of a Blast Furnace Photographed at Colorado Fuel and Iron Corporation.** (*Blast Furnace Steel Plant*, 1958, **46**, May, 482–483). A short account is given of the photographing of the stock line armour on a blast furnace by lowering a camera and flashgun through the top during a shut down.—B. G. B.

**The Low Shaft Furnace.** H. Malcor. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 13). The advantages and disadvantages of the low-shaft furnace are briefly set out. The use of fine ores, dust production, agglomeration by extrusion and ore-coal agglomeration are surveyed and the use of small coke, semi-coke and non-coking coals is considered, also oxygen enrichment and top pressure. A brief economic study is added.

**A Brief Report on Research Carried out on the Ougrée Low Shaft Blast-Furnace.** (*Met. Ital.*, 1958, **50**, Feb., 59–64). [In French]. A brief account is given of the findings with the Ougrée low shaft blast-furnace after 3 years of research on the plant. Diagrams and photographs of the installation are reproduced.—M. D. J. B.

**Use of Sponge Iron in a Low-Shaft Furnace in Mexico. Operational Results.** J. W. Ehrenberg. (*Second National Congress of the Iron and Steel Industry*, [Mexico], 1957, 183–188). Data from pilot furnace trials support the conclusion that the combination of the sponge iron process with a low-shaft furnace meets regional and national economic requirements. **Electric Production of Pig Iron and Steel.** C. G. Dauchat. (251–260). Modern processes are discussed.

**Production of Low Phosphorus Foundry Iron from High Phosphorus Iron Ores.** R. I. Higgins and J. C. Billington. (*B.C.I.R.A.J. Res. Dev.*, 1958, **7**, Feb., 171–187). A process for dephosphorization of direct blast furnace metal was sought. $O_2$ top blowing appeared suitable. A small scale test with 175-lb of metal established conditions for minimum C loss and trials on 2–25 t of metal confirmed that by conforming to them each 1% P need not require loss of more than 1% C in its removal. Some recarburization would even then be necessary and with sufficient superheat this can be effected with coke breeze in a rotary vessel. The Kaldo converter is suitable both for this purpose and for oxygen surface blowing. Trials on the 27-t scale were successful.

**The Production of Pig Iron with 0·5–1·5% Phosphorus by the L.D. Process.** H. Trenkler. (*Meeting in Belgium and Luxembourg*,1958, *Liège, preprint*, pp. 12). Four series of tests are reported on the conversion of electric furnace irons produced from forge iron and ferrophosphorus. The operation is carried out with two slags using the second of one batch for the first of the next. After 10 min., fine ore was added and the converter tipped. After removal of slag more lime and fluxes were added, the lime used being 140–160 Kg/t steel. Near the end of the first stage the P was below 0·4%. Comparison with Kaldo and Rotor processes is made, consumption of refractories is increased 36% on account of the longer time taken by the high-phosphorus iron. The steel properties are given and are the same as those of normal L.D. steel. [Discussion]. M. Lambert (pp. 2).

**Factors Affecting the Transformation of Carbon in Pig Iron.** L. I. Slepushova. (*Stal'*, 1958, (4), 298–300). There has been a tendency for pig irons to have higher carbon contents to the detriment of properties for machine part production. Treatment outside the blast furnace is investigated including decanting from ladle to ladle.—R. S.

## PROPERTIES, TREATMENT, AND USE OF SLAGS

**The Relative Resistances to Basic Slags of Magnesite and Dolomite.** W. F. Ford and J. White. (*Refract. J.*, 1958, **34**, Apr., 171–174.) Approximations to the $CaO$–$MgO$–$Fe_2O_3$ system diagram are obtained and superiority of MgO over dolomite at increasing temperatures is indicated, though the effect of solid lime in giving a less fluid slag may favour dolomite in some circumstances.

**Hydraulic Activity of Granulated Slags.** N. A. Toropov and B. V. Volkonskii. (**Doklady A. N.*, 1949, **66**, (1) 95–97). Vitreous and slowly cooled slags were compared and the former annealed at 850° and 1300° C. Compressive strengths and heats of solution are given. The crystalline slags showed the greater activity.

## DIRECT PROCESSES

**Direct Reduction of Iron Ores: Developments in Europe.** A Scortecci. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 39). A review of processes originating in Europe. (160 refs.)

**Direct Reduction Processes for Iron Ore.** P. E. Cavanagh. (*Meeting in Belgium and Luxembourg*, 1958, *Luxembourg, preprint*, pp. 9). A review of processes actually in use and those being developed is given. The use of sponge iron as synthetic scrap is mentioned and processes developed by the Ontario Research Foundation are described. The O.R.F. Direct Steel Process is a process of reducing poor ore on a travelling grate, the cake being laminated directly into a strip. The Jet Smelting process consists of treatment of pulverised ore with natural gas and $O_2$, the reduced material is directed downwards into a bath of metal and slag.

**Procedures for the Direct Reduction of Iron Ore and Smelting in General.** E. I. Aguilar. (*Second Nat. Congress Iron and Steel Industry*, [Mexico], 1957, 101–109). An account of the H–iron process.

**Refining Pig Iron with Oxygen According to the Kaldo Process.** B. Kalling and F. Johansson. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 12). Use of the process at Domnarvet is outlined and the control of iron in the slag, refractories and fumes are considered. The process might be extended to the production of steels without recarburizing. Economics of the process are discussed.

**The Rotor Process.** R. Graef and L. von Bogdandy. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint, pp.* 8). The metallurgy of the process, the method of control and industrial operation are considered including lay-out of plant and auxiliary installations. Details of operation with two lances and the effect on fumes and other variables are reviewed, and control of depth of immersion and control of $O_2$ discharge. A method of bath temperature measurement is then given. Finally the results obtained from two rotors are discussed.

## PRODUCTION OF STEEL

**The New Paths in Steelmaking.** F. Gonzalez V. (*First National Congress of the Iron and Steel Industry* [*Mexico*], 1955, 143–155). A brief account of modern developments and techniques in iron and steel making is given.

**A Soviet Delegate's Account of Steelmaking in England.** N. G. Veselkov. (**Metallurg*, 1957, (4), 44–47).

**Economic Efficiency of the Use of Oxygen.** V. F. Andreev. (*Stal'*, 1958, (6), 561–568). O.H. furnaces, converters, arc furnaces and blast furnaces are all reviewed and methods of reducing the cost of $O_2$ are discussed.—R. S.

**The Pamiers Plant of Société Métallurgique d'Imphy.** (*Mét. Constr. Mécan.*, 1958, **90**, Mar., 171–175). The development of this plant, which manufactures special steels, is described.

**Project for the Establishment of a Small Integrated Steel Works.** F. Gonzalez (361–365). The need for this type of plant in Mexico is explained and estimates for one near La Encarnacion are given. **Pioneers in New Developments in a Plant for Special Steels. Sixth Committee: Various Topics.** H. G. de Young (317–335). A detailed account of four new processes included in the programme of expansion at Atlas Steels Ltd., Canada. These are: continuous casting, deseaming by the Linde process, Sendzimir planetary mill, annealing and descaling line.

**French Steel Industries Inaugurate New Experimental Station at Maizières-les-Metz.** H. G. Cordero (*Met. Bull.*, 1958, May 23, 21–24). An account of the ceremonies with illustrations.

**The Creation of a New Electrometallurgical Centre in France.** (*J. Four Elect.*, 1957, **62**, Nov.-Dec., 195–196). A centre is being developed in the neighbourhood of the village of L'Ardoise for the manufacture of ferro-alloys, special steels and associated products. A plant for the manufacture of low-carbon ferrochrome has been in operation since 1952, and other works are being constructed or planned.—L. D. H.

**Conversion of Pig Iron by Bottom Blowing.** J. Daubersy and A. Decker. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 10). Oxygen enriched blast working is reviewed, also $O_2$-steam in one or several stages, double slagging, desulphurization by the normal process or with siphon ladles, or in the converter with low-S lime. The process is then summarized and refractories, analytical control or spectrography, and the steel properties resulting are considered. The future outlook is surveyed.

**French Experience with Bottom Blown Converters.** M. Allard. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 5). Work by I.R.S.I.D. is summarized. Correct profiles for converters with large bottoms, a desulphurization process with powdered lime giving a low-S charge even with high-S blast furnace iron: injection installations for powdered materials, minimizing the disadvantages of high-Si and also giving control of $N_2$. With these and limited blast enrichment quality can be maintained.

**Theoretical and Practical Hydrodynamic Study of the Bath Movements in the Bottom-Blown Converter.** P. Leroy and G. Cohen de Lara. (*Rev. Mét.*, 1958, **55**, Jan., 75–97). This is the first section of a paper dealing with bath movements, and based on a study of models of circular section. In considering the influence of the geometry of the converter on bath movements, it is recommended that the blast zone should be as wide as possible. A later communication will include an investigation of vessels with an oval section.—L. D. H.

**Progress in Basic Oxygen Steel Making and Economics.** N. Retlaw. (*Iron Steel Rev.*, 1958, **1**, Apr., 27–29). A discussion of the L.D. process with a list of installations in Europe and the U.S.

**The Refining of Low-Phosphorus Pig Iron in the Bottom Blown Converter.** H. Kosmider, A. Weyel, and H. Neuhaus. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 8). The amount of scrap that can be melted during refining of pig iron of different P contents using blast enrichment is shown and trials on low-P irons with $O_2$–steam are reported. A 22-t cast takes 6–8 min. and steel comparable with the best O.H. steel is obtained. The chemistry of the basic converter and O.H. processes were studied and lime used and slag formed was related to P and S. The L.D. process is then compared with the basic Bessemer using 32% $O_2$, $O_2$–steam and air and productivity and the brown fume problem are examined.

**Special Blowing Techniques for the Basic Bessemer Converter Used at Aciéries et Minières de la Sambre at Monceau-sur-Sambre.** M. Demaret. (*Meeting in Belgium and Luxembourg*, 1958, *Liège, preprint*, pp. 9). The oxygen plant is described and data on $O_2$–$CO_2$ and $O_2$–steam blowing are presented.

**Top Blowing at the Petrov Plant.** N. I. Beda and N. K. Kotov. (*Stal'*, 1958, (6), 518–519). 1030 Trials were made with rimming steel and without removal of slag. Ingot yield increased, heat time was reduced by 3 min. and S and P were unchanged, also the chrome–magnesite lining was not more greatly attacked. Ore-limestone briquettes were used in 60 trials, which accelerated slag formation and controlled temperature, no water being needed for cooling. Heat time was reduced by 2 mins. and the amount of steel overheated (above 1630° C) was halved. To attain not more than 0·04% S the iron should contain not more than 0·05%, not less than 1·5% Mn and not more than 0·6–0·7% Si.—R. S.

**New IRSID Process for Refining Phosphorus-Bearing Pig Irons with Pure Oxygen and Lime Powder.**—B. Trentini and M. Allard. (*Rev. Mét.*, 1958, **55**, Jan., 67–74). Small-scale trials are described in which phosphorus-bearing irons—in particular Thomas irons—were refined by a new process, using a 99·5% oxygen jet containing a suspension of finely-divided lime. The oxygen lance, above the 3-ton converter, was water cooled. 70% desulphurization was easily achieved, and a very low phosphorus content could be obtained without previous removal of all the carbon. Hence the process could be regulated to finish at various carbon levels. Nitrogen was of the order of 0·001%.—L. D. H.

**Oxygen-Steam Mixed Blast in the Basic Converters at Espérance-Longdoz.** J. Daubersy. (*Iron Coal Trades Rev.*, 1958, **176**, June 13, 1439–1441). A brief account of the working of the basic Bessemers and the development and working of the mixed blast process is given.

**Spectrographic Control of Oxygen-Steam Blow Heats.** R. Breckpot and B. Juchniewicz. (**27th Congress of Industrial Chemistry*, 1954, *Brussels, reprint*). Basic Bessemer blows were examined spectrographically with a view to following P removal using $Na_2CO_3$ additions. Red, violet, and polychromatic traces and the red:violet ratio were related to dephosphorization. A satisfactory turn-down signal was obtained.

**Gas Saturation Capacity of Converter Steel Blown with Oxygen.** S. G. Afanas'ev and M. M. Shumov. (*Stal*, 1958, (5), 405–410). It is concluded that it is essential to use high purity $O_2$ for top blowing and that when working with a blast enriched up to 45% and using ore as a coolant, steel can be produced with the same $N_2$ content as that made by top blowing with 96% purity $O_2$. The amount of $O_2$ in the metal depends on C content, low carbon steels show increased $O_2$ content and more iron oxides in the slag.

**A Study on the Dephosphorisation Equilibrium in the Oxygen Converter.** E. Homma. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 960–962).

**On the Overheating of Low Bessemer Steels.** P. Ya. Sorokin. (*Lit. Proizv.*, 1955, (8), 23–25). [In Russian]. In spite of widely held opinion, the overheating of low Bessemer steel by the air blown in does not arise from combustion of the CO to $CO_2$ in the converter chamber, but from the loss by combustion of the slag-forming mixtures and of iron during the blow.—L. H.

**Quality of Basic Converter Rimming Steel Blown with Oxygen.** S. G. Afanas'ev, N. I. Beda, A. A. Mitrofanov, P. Ya. Ryzhkov, N. K. Kotov and S. N. Filippov. (*Kislorod*, 1957, **10**, (4), 5–13). Rimming steel produced in the converter has a somewhat higher N and P content than O.H. steel of the same grade. The P, N and O contents of basic Bessemer metal are markedly lower than those of acid Bessemer steel. The mechanical working behaviour of basic Bessemer steel of rimming grade is identical to that of O.H. rimming steel. The yield is also similar. Micro- and macro-structures and mechanical properties are also similar, though the tensile properties of basic Bessemer metal are somewhat higher and the ductile properties somewhat lower than in the case of O.H. steel. Impact strength of basic Bessemer steel at sub-zero temperatures and after ageing is somewhat lower than that of O.H. steel. Cold bend tests on basic Bessemer metal were satisfactory. Weldability and cold drawing properties of basic Bessemer steel were also found to be satisfactory.—R. S.

**Technical and Economic Comparison of Open Hearth and Rotor Processes of Steel Production.** I. P. Bardin and M. M. Pischikov. (*Kislorod*, 1957, **10**, (5), 1–6). After citing the reasons for the developments at Oberhausen, the article describes Russian comparisons of the rotor and O.H. methods. The Zaporozhstal plant made casts in 200-t furnaces using high proportions of hot metal (right up to 100%) and oxygen. The P content of the pig iron was 0·3% max. It was found that S is more easily removed in the rotor process than in the O.H. due to high slag temperatures and the contact between the metal and the oxidizing gases free from S. Steel costs and capital costs were taken into account under Russian conditions to effect a comparison. Bardin concludes that, on the basis of available data, it does not appear

possible to draw up absolutely final conclusions regarding the rotor process. However, even a general comparison makes it justifiable to assume that the rotor process does not have any substantial advantages over the O.H. process using a high percentage of hot metal in the charge. It is, however, admitted that the special sulphur conditions applicable to German raw materials may make the rotor process much more worth while in Germany than in the U.S.S.R.—R. S.

**Results of Co-Operative Trials on All-Basic Furnace Roofs.** B.I.S.R.A. and Brit. Ceram. Res. Assoc. (*Ceramics*, 1958, **9**, Feb., 18–19). Roof trials at four steelworks with various types of brick, so arranged as to obtain a comparison of at least 2 brick varieties in the same furnace in each of the 11 trials, are outlined and the importance of volume stability at 1700° C and good refractoriness-under-load values or low creep established. Iron oxide bursting index was not found to be a critical property.

**Aerodynamic Constitution of the O.H. Furnace. VII. Functions of the Burner Jet.** H. A. Hasimoto. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1094–1098). Model studies show that the best position for the burner jet is inserted at a quarter of the chamber width and set at a height of 30% of the furnace width at an inclination of 12%. The effects on flow of twin jets are examined, and the flame lengths are found to be shortened by increasing the jet fluxes and slight convergence of the burner directions.—K. E. J.

**Metallurgical Comparison of the Tilting and Stationary Open Hearth Furnaces. Process of Desulphurisation.** M. Ito. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 967–969).—K. E. J.

**Reconstruction of an O.H. Furnace.** K. Ikuma. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 962–963).—K. E. J.

**The Quality of Steel Produced from Pig Iron Smelted with Constant Moisture Blast.** M. I. Kolosov, A. N. Morozov, A. I. Stroganov, Yu. A. Popov, O. Ya. Vainshtein and N. V. Keis. (*Stal'*, 1958, (1), 24–27). Using the scrap-ore process in the O.H. furnace, the $H_2$ content in the pig iron has no influence on the content in the metal during melting and casting. A direct relationship between flake sensitivity and $H_2$ content of liquid metal has not been found. Cooling at Chelyabinsk for steels susceptible to flaking is arranged to eliminate flaking whatever the source of the pig-iron. The macrostructure of the rolled billets is independent of blast humidity. The cooling method is not described.—R. S.

**Gasification with Air Enriched in Oxygen.** R. Alleyrac, L. de St. Martin, R. Veuve and P. Leroy. (*Publ. IRSID*, 1957, 173A, Sept., pp. 74). Use at the Senelle O.H. furnace plant is surveyed, with details of analytical methods.

**The Use of Natural Gas in Open Hearth Furnaces. I.** V. Ripeanu. (*Met. Constr. Masini*, 1957, **9**, (9), 11–18). [In Rumanian]. Native methane contains 98/99% $CH_4$ and between 1 and 2% of $N_2$, $H_2O$ and $O_2$. Its calorific value is 8500 Kcal/m³. Owing to the slow combustion process of methane gas, an optimum mixture of air and gas must always be maintained. Another disadvantage is its lack of luminosity. This phenomenon of non-luminosity (in view of this gas having the maximum carbon content possible), can be explained by the fact that $CH_4$ dissociates endothermically between 950–1150° C into $C + 2H_2$–880 k/cal. with carbon black formation. However in using carburisers, the combustion can be adapted with advantage to O.H. furnaces.—L. H.

**The Use of Natural Gas in Open Hearth Furnaces. II.** V. Ripeanu. (*Met. Constr. Masini*, 1957, **9**, (10), 9–13). [In Rumanian]. The second part of the investigation is a report of the reconstruction of the O.H. furnaces for $CH_4$ firing in Italy, Poland, Western Germany, USSR and U.S.A.

For local conditions, it is recommended that furnaces of 60-t with an area of the bath surface of 32 m² and one gas uptake should use methane gas in heating.

It is recommended further that carburetting of cold natural gas with 20 to 25% fuel oil should be employed.—L. H.

**Operating Open Hearth Furnaces on High Calorific (Coke Oven) Low Pressure Hot Gas.** V. S. Kocho, V. I. Grankovskii, Y. D. Molchanov and E. A. Plashchenko. (*Metallurg*, 1958, (2), 9–12). All O.H. furnaces at the Voroshilov plant were fired with half the amount of blast furnace gas compared with normal (3000 m³/h in 250-t furnaces and 4500 m³/h in 500-t furnaces) and the normal amount of coke oven gas. By increasing the cross-sectional area of the pots of the 250-t furnaces from 0·41 to 0·48 m² and reducing the consumption of blast furnace gas, the same high preheat in gas and air checkers was obtained (1350° C). The use of fan air made it possible to work with an excess air factor of one. Slag pocket life was increased from 200–250 to 400 heats. Trial heats were run with preheated coke-oven gas only in the 500-t furnaces. Fuel consumption was reduced by 60 lb/t and tap-to-tap time was reduced by 40 min. On furnaces with smaller checker volume and little reserve of draught, thermal conditions are improved by firing with coke-oven gas. When blast furnace gas is not used, high velocity compressed air must be fed through the gas port end and blast furnace gas must be fed during reversals.

**Accelerating Combustion in the O.H. Furnace by Auxiliary Jets.** A. Hasimoto. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 911–912).

**Oxygen in the Open Hearth Process.** K. M. Trubetskov. (*Kislorod*, 1957, **10**, (3), 1–8). The article describes types of oxygen burners and lances and the thermal conditions in the furnace when oxygen is fed to the furnace chamber. Data are given on the relationship between furnace productivity and fuel consumption for varying degrees of oxygen enrichment of the fuel. The use of oxygen for direct oxidation of the bath and methods of lancing and introducing oxygen through the roof are described. In Russia, oxygen is fed to the flame right from the beginning of charging until melt-down and even to the beginning of the pure boil when producing rimming steel and some killed steels.—R. S.

**The Utilisation of Tonnage Oxygen in the O.H. in the Chiba Iron and Steel Works.** M. Katayama. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1035–1037). Operating data over three years are given; the $O_2$ consumption rose from 0 to 32·2 m³/t. In that time the production per furnace hour rose from 11·2 to 22·6 t, and fuel consumption fell from 1153 to 610 + $10^3$ kcal/t.—K. E. J.

**Studies on Melting Practice in Tilting O.H. Furnaces. On the Change of Bath Conditions during Oxygen Blowing.** M. Nishiwaki. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 1137–1039).

**Desulphurisation of Molten Steel.** Y. Nagano. (*Tetsu-to-Hagane*, 1957, **43**, Sept., 966–967). A diagram is shown giving a scattered relationship between (S)/[S] and $(CaO)/(SiO_2)$. Partial correlation coefficients are given between (S)/[S] and various constituents of the slag.—K. E. J.

**Heat Balance in The Open Hearth.** F. Savioli, A. Ramaciotti and L. Pompilio. (*Met. Ital.*, 1957, **49**, Sept., 661–668). [In Italian]. The authors organize the problem of heat utilization in O.H. furnaces. The conception of heat balance has been taken a step further by the use of instruments and continuous furnace analyses. A new method of expressing the results of furnace analyses is suggested in which a series of efficiency numbers is given for the different periods of the heat. The efficiency numbers can be combined to determine the total efficiency of the furnace. An example is given.—M. D. J. B.

**The Determination of the Main Parameters of Open-Hearth Furnaces,** by S. Cernoch, jun. (*Collected Scientific Monographs of the Technical High School in Kosice*. 1957, 49–63). The author describes previous methods of determining these dimensions and points out their shortcomings. He then outlines a new basic method of calculating furnace operating conditions built up on the calculation of the maximum calorific output of the furnace. He discusses the effect of various designs of roof and the calculation of the main measurements of the flues, and with the aid of good graphical illustration, he explains the mathematical calculations of the main measurements in relation to the overall size of the furnace. A clear exposition of a very thorough and exact method of calculating all the measurements necessary for furnace design.—M. deo. T.

**Heat Exchange in Regenerators,** J. Spal. (*Collected Scientific Monographs of the Technical High School in Kosice*. 1957, 65–85). The author describes heat-exchange in regenerators as a periodic process, and the active factors governing the idle period during periodic changes in heat in relation to the checker work of a O.H. furnace. He thoroughly examines normal heat movements, and temperature and heat variations in a homogeneous checker, heat exchange, and heat distribution of and in the checker, and their causes and effects. It would seem to be a definite contribution to a more methodical and exact approach to problems arising in regenerator physics; it is well illustrated graphically, and the new method of mathematical calculation of the thermal reactions in a regenerator and of thermal output is fully elaborated.—M. deo. T.

**Technical and Economic Characteristics of Waste Heat Boilers.** R. Kremer. (*Hutník*, 1957, **7**, (9), 305–310). [In Czech]. Economic and technological aspects of waste heat utilization are discussed, with special reference to developments in the use of boilers for heat recovery in the Soviet steel industry.—F. F.

**Equipment for the Recovery of Waste Heat From Open-Hearth Furnaces.** M. Kröhn. (*Hutník*, 1957, **7**, (11), 375–381). [In Czech]. Waste-heat boiler practice and its advantages are discussed. Various types of boilers are considered.—F. F.

**Manufacture of Steel in the Arc Furnace.** J. Colin. (*Centre d'Études Sidérur.*, 1957, *Electric Steelmaking*, **2**, 1–80). A comprehensive review of steelmaking in arc furnaces is presented. The general principles are first reviewed and then considered in detail. Charging is first discussed and the importance of the preparation of the change and its compaction are explained. Melting and dephosporization are next described and the influence of Mn is stressed. Deoxidation, the formation of inclusions, gas evolution and desulphurization are discussed. Steelmaking in basic and acid furnaces is reviewed. Refractory linings for arc furnaces are considered. The organization of an electric steel making plant is discussed.—B. G. B.

**Large Arc Furnaces.** (*Metallurgia*, 1957, **56**, Dec., 275–276). A description is given of a 90-t direct arc furnace made by Metalectric Furnaces Ltd.—A. D. H.

**South Africa's First Large Arc Furnace.** (*Metallurgia*, 1957, **56**, Dec., 293–294). A 70 t E.F.C.O. arc furnace at the Pretoria works of the South African Iron and Steel Corporation is described.—A. D. H.

**Electrical Equipment.** G. Danielou. (*Centre d'Études Sidérur.*, 1957, *Electric Steelmaking*, **1**, 1–29). The fundamental factors affecting the consumption of electric power in arc furnaces are first considered; these include stability and reactance. High voltage and low voltage equipment is reviewed. Commercial systems of arc furnace control are described. Induction stirring of liquid steel is briefly mentioned.—B. G. B.

**Electrodes.** F. N. Pensa. *Centre d'Études Sidérur.* 1957, *Electric Steelmaking*, **1**, 1–51). A comprehensive review is presented of electrodes for use in electric arc furnaces. The manufacture, selection, and performance of amorphous carbon, graphite and Soderberg type electrodes are described and the advantages and disadvantages of these three types are discussed. Standard nipples, dimensions and other properties of electrodes are given in tabular form.—B. G. B.

**Electrical and Thermal Behaviour of Arc Furnaces.** R. Hugot. (*Centre d'Études Sidérur.*, 1957, *Electric Steelmaking*, **1**, 1–23).

Factors affecting the operation of an arc furnace for steelmaking are considered and a thermal balance is obtained. The energy distribution during typical steelmaking heats is discussed with examples. Acid and Duplex practice are considered.—B. G. B.

**Construction of Electric Arc Furnaces.** C. Barbazanges and A. Richard. (*Centre d'Études Sidérur.*, 1957, *Electric Steelmaking*, **1**, 1–40). Factors influencing the design of arc furnaces, i.e. dimensions, type of current, number of electrodes etc. are first considered. The methods available for charging arc furnaces and their effect on furnace design are reviewed. A detailed examination of the various types of construction in service is made. Modern views, in particular American, on refractory linings are reported.—B. G. B.

**Study of High Frequency Furnaces and Indirect Arc Furnaces.** L. Babel. (*Centre d'Études Sidérur.*, 1957, *Electric Steelmaking*, **2**, 1–30). A comparison is made between these two types of furnace. Details are given of refractory linings furnace construction, operation and performance.—B. G. B.

**Arc Furnaces and Mains Fluctuation.** B. C. Robinson and A. I. Winder. (*Elect. Times*, 1958, **133**, Feb. 20, 293–294). Effects on a 60 t furnace are described.

**The Construction of High Frequency Induction Furnaces.** J. Minssieux. (*Centre d'Études Sidér.*, 1957, *Electric Steelmaking*, **2**, 1–33). The theoretical principles of high frequency induction heating are first considered. A number of electrical circuits for the generation of high frequency current are described. Conventional and vacuum furnace construction are reported.—B. G. B.

**The Use of Chromium Ore instead of Ferrochrome in Steelmaking.** V. Keclík. (*Hutník*, 1957, **7**, (7), 221–226). [In Czech]. The theoretical and economic aspects of cheapening electric steel production by the use of ferrochrome substitutes are discussed. Experiments carried out in Czechoslovakia have yielded satisfactory results; details are given. It is suggested that the method may yield good results also with low-alloy steels produced in the O.H. furnace.—P. F.

**The Electrosteel–Slag–Alloy Process (Slag Reduction Process) for the Smelting of Steel in the Basic Electric Arc Furnace.** K. Fellcht. (*Neue Hütte*, 1957, **2**, Dec., 731–737). The operation of standard electric arc furnaces is discussed with special emphasis on capacity and alloy metal saving. A comparison is then made between the new slag reduction process as practised at the "Wilhelm Florin" Steel Works at Hennigsdorf and conventional smelting processes, to the advantage of the former.

**The Production of High-Quality Steels by a Slag-Reaction Alloy Process, and the Results Achieved.** H. J. Eckstein. (*Neue Hütte*, 1957, **2**, Dec., 737–749). The "slag-alloy" process is described. Results of metallurgical tests, comparisons of quality, and operational data to date are reported to demonstrate the advantages of the process in the production of alloy steels.—L. J. L.

**Transformers for Direct Arc Steel Melting Furnaces.** F. A. Smith. (*English Elect. J.*, 1957, **15**, Dec., 3–16).

**Extraction of Vanadium from a High Phosphorus Iron.** A. Yu Polyakov and A. M. Samarin. (*Izvest. Akad. Nauk, Otdel. Tekhn.*, 1957, (6), 18–26). [In Russian]. Extraction of V from a low-silicon (up to 0·45%) and high-phosphorus (up to 2%) iron by blowing with air at temperatures about 1200° C with the formation of very viscous slags containing not less than 3·5% V was investigated. The experiments were carried out on synthetic irons in a high-frequency furnace of 40 kg capacity. The compositions of irons and slags are given. The results obtained indicated that the production of V slags (3–3·5% V) suitable for further treatment by blowing with air of high-P pig iron containing 0·08–0·1% V is practicable. The following limiting conditions for the process were established: Si content of iron should not exceed 0·25% and that of Mn 1%; low temperature of blow in order to prevent oxidation of carbon and to produce a viscous slag; prevention of dilution of the slag by other oxides ($SiO_2$ and CaO). On the basis of the results obtained, a technological scheme for treatment of high-P pig with extraction of V is outlined.

**Development of Special Steels Containing Nickel for Underground Use in the Lorraine Iron Mines.** E. Majois. (*Rev. Nickel*, 1957, **23**, Jan.-Mar., 9–12). Various conveyor parts are shown and the composition of various AFNOR Ni steels are given with their properties and uses.

**Stainless Steels Including Other Ferrous Alloys.** W. A. Luce. (*Ind. Eng. Chem.*, 1957, **49**, Sept., Part II, 1643–1652). A review of properties and uses in chemical industry, with notes on welding and stress corrosion and on high-silicon iron, Fe-Ni alloys and on austenitic Fe-Mn steel. (137 references).

**Progress in Stainless and Heat-Resisting Steels.** J. Lomas. (*Eng. Boiler House Rev.*, 1958, **73**, 51–52). A general survey.

**Manganese Steels.** F. Javier Mariñas. (*Met. Elect.*, 1957, **21**, Dec., 66–72). [In Spanish]. A brief account is given of the effects of Mn upon the structure, properties, heat-treatment and uses of this group of steels which range from 0·25 to 14% Mn.

**The Latest Edgar Allen Special Alloy Tool Steels.** (*Edgar Allen News*, 1958, **37**, Feb., 28–30; Mar., 56–57). Minerva L.C. Steel, Imperial Tool Steel, Maxmith Steel, Superdraw Steel, No. 5 Hot Die Steel, Maximum Steel, A.M. 3 Die Steel, Lominium Steel, A.M. 1 Special Die Steel, Maxnap steel and Y.W.A. steel are described.

**Structural Steel with a Specially High Strength.** J. Korecký. (*Hutník*, 1957, **7**, (8), 257–258). [In Czech]. Properties, production and applications of standard high-strength low alloy steels as used in Czechoslovakia, the Soviet Union and America are discussed.—P. F.

**Boron Steels.** A. Michel. (*Techn. Mod.*, 1957, **49**, Oct., 525–528). The development, use and applications of low alloy steels containing boron is discussed.—B. C. W.

**High Speed Steels: Types and Treatments.** (*Mech. World*, 1958, **138**, Feb., 76–78). Composition and properties are indicated.

**Making a Forging-Ingot Mould with Skeleton Pattern.** F. H. Gartland. (*Brit. Found.*, 1957, **50**, Nov., 560–562). A brief description is given of a method used to make a forging ingot mould weighing 45 t.—B. C. W.

**Corner Scale in Ingot Moulds.** (*Foundry Trade J.*, 1957, **103**, Nov. 14, 589). A method of eliminating the deposit of hard high-P iron, known as corner scale, by a process of blowing air into the mould during solidification is described.

**How to Pour Steel into Ingot Moulds.** A. Děkanovský. (*Hutník*, 1957, **7**, (8), 259–266). [In Czech]. The advantages and disadvantages of top and bottom pouring with effervescent and killed steels are analysed.

**Casting of Ingots of Special Steels.** G. Grenier. (*Echo Mines*, 1957, Nov., 651–652). Continuous casting is compared with the normal method for structures produced and distribution of inclusions and segregations. Alternatives such as smelting of ingot tops, vacuum casting, gas absorption and rolling faults are also briefly reviewed.

**Continuous Casting at Low Moor.** (*Met. Bull.*, 1958, Feb. 11, 24). The machine is illustrated and described.

**Continuous Casting Plant for Steel.** (*Engineer*, 1958, **205**, Mar. 7, 372–373). A description of the plant being erected for Terni Societa per l' Industria e l'Electricita, Terni, Italy, is given.

**Method of Continuous Casting in Use in the U.S.S.R.** F. Jansch. (*Hutn. Listy*, 1957, **12**, (11), 1033–1039). [In Czech]. After a brief survey of continuous casting methods in use in countries other than the Soviet Union, several continuous and semicontinuous installations developed in the U.S.S.R. are reviewed. The potentialities of Soviet experience in the projected construction of continuous casting plant in Czechoslovakia are discussed.—P. F.

**The Significance of Continuous Casting of Steel.** V. Čížek. (*Hutník*, 1957, **7**, (7), 236–241). [In Czech]. Technological and economic aspects are discussed, mainly in the light of Soviet and other recent publications.

**The Effect of Different Mn, Si and Al-based Deoxidants on the Quantity and Distribution of Non-Metallic Inclusions in Steel.** T. Myslivec. (*Hutn. Listy*, 1957, **12**, (11), 989–1000). [In Czech]. On the basis of microanalysis, electron-micrography and mechanical tests it is shown that complex deoxidants of the FeMnSiAl type are preferable to FeMnSi alloys from the point of view of wide applicability, whether judged on the basis of the quantity or composition and structure of the inclusions. Small subsequent additions of Al were found to be beneficial with all deoxidants, the alumina formed in the iron tending to inhibit the formation of heavy, refractory silicates.—P. F.

**The Finished Product and The Responsibility of the Steel Plant.** M. Signora. (*Met. Ital.*, 1957, **49**, Sept., 223–230). [In Italian]. The author gives a detailed review of ingot defects and shows that these are generally responsible for poor quantity in the finished product. Measures which can and should be taken to improve ingot quality are discussed.—M. D. J. B.

**Endothermics Raise Ingot Yields. II: Drop-in Feeders.** G. N. Cherry and N. J. Griffiths. (*Brit. Steel.*, 1958, **24**, May, 141–147). The use of sleeves is described in an illustrated article and discussed for various forms of ingot mould. Costs are extensively considered and a balance sheet is drawn up and savings are estimated showing a difference of £1 4*s*. 9*d*. per t. on an output of 1680 t.

**New Experiments in North Urals with Exothermic Mixtures.** N. F. Dubrov. (*Stal'*, 1958, (4), 378). A note stating that the best results have been obtained with mixtures of equal volumes of Al powder, millscale and Portland cement. The mixture is made up with 15–20% water and plugs or pads or facings 15–25 mm thick are shaped from it. The height of the feeder zone was halved.

**Recent Experience in the Continuous Casting of Steel.** H. Krainer and B. Tarmann. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 11; *J.I.S.I.*, 1958, **190**, Oct., 105–111). [This Issue]. The Bohler A.G. Plant at Kapfenberg is mainly described. Methods of study of metal cooling conditions are reported consisting of cutting off the bar near the lower end of the cone of solidification, tracer studies with radio-P or radio-S and addition of Pb. A section on defects is added, overheating of the metal and cooling irregularities are the principal dangers.

**Some Features of Continuous Casting at Barrow.** I. M. D. Halliday. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 7). A pilot plant casting 2 to 4 in. square billets or 6 × 2 in. slabs is described. Preheated ladles and the cooling sprays below the mould are described and bending rolls to give horizontal discharge have been developed.

**Continuous Casting on the B.I.S.R.A. Experimental Plant.** G. Fenton and J. Pearson. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 11). The heated tundish and elastic mould suspension are particularly described. Moulds 75 and 100 mm square and 45 × 230 mm have been used to cast ingots of maximum length 7 m. The properties of the ingots are given.

**Continuous Casting of Steel in France, 1958.** P. Thomas. (*J.I.S.I.*, 1958, **190**, Oct., 112–113. [This Issue]; *Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 5). Three plants are surveyed, J. Holtzer at Unieux, Estabs. Cail at Denain and Hauts Fourneaux et Forges d'Allevard.

**Continuous Casting at the Centre National de Recherches Métallurgiques, Section du Hainaut.** J. Zaeytydt. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 7; *J.I.S.I.*, 1958, **190**, Oct., 165–168). [This Issue]. A unit built 1956–57 is described, intended to cast ingots of killed basic Bessemer steel and electric carbon or low-alloy steels from

75 to 125 mm square. A second unit is now being built to cast rimming basic Bessemer ingots from 120 to 200 mm square, or slabs 120 × 350 mm. The various parts of the installation are described.

**Continuous Casting of Steel in Western Germany.** K. G. Speith and A. Bungeroth. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 8; *J.I.S.I.*, 1958, **190**, Oct., 158–161). [This Issue]. The rates of casting of killed and rimming steels and O.H., electric and basic Bessemer steels are discussed and rates of extraction and solidification. Siphon ladles and nozzle ladles are compared and the use of an intermediate receiver is considered. The mould and its suspension is then reviewed and various possible improvements are outlined.

**[The Continuous Casting Process at Novo Tula].** N. F. Dubrov. (*Stal'*, 1958, (4), 331). Two heats were recently produced of transformer steel (without Al) as 6 × 19 in. slabs and one heat as 8 × 8 in. billets. Factors involved and measurements made are noted, but no values are given.—R. S.

**Continuous Casting at Atlas Steels Ltd.** G. C. Olson. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 13).

**Experience in Combined Secondary Cooling of the Continuously Cast Ingot.** A. D. Akimenko, A. M. Makushin, A. A. Skvortsov, A. V. Khrilkov, and L. B. Shenderov. (*Stal'*, 1958, (6), 509–511). A method of cooling with a two-phase air-water mixture is described. This improves ingot quality, especially by eliminating the longitudinal cracks previously the main cause of defects at the Red October plant.—R. S.

**Control of Flow of Liquid Metal during Continuous Casting.** W. Siegfried and B. Broniewski. (*Meeting in Belgium and Luxembourg*, 1958, *Charleroi, preprint*, pp. 10; *J.I.S.I.*, 1958, **190**, Oct., 162–165). [This Issue]. An electromagnetic control system is described for a rolling mill producing welding rod. The pumping system is discussed.

**An Examination of the Quality of Transformer Steel Produced by Continuous Casting.** N. M. Lopatyshkin, V. S. Rutes, and G. V. Gurskii. (*Stal'*, 1958, (5), 417–425). Rectangular or square billets are produced without impairment of electrical properties. As ductility is high at 950–1000°, at high speeds, it is possible to effect partial reduction of the billets in the pinch rolls. The depth of the liquid zone in the secondary cooling area must be known. Structure depends mainly on temperature. Siliceous ferrite tends to form hot cracks, but porosity and internal cracks seal up on rolling. Slabs with 4–4·5% Si must be tempered at 650–700° to relieve internal stress and must be slowly cooled from 300–50° C. Square billets are less prone to cracking during cooling. Flame cutting is possible only above 300–400° C. Advantages of continuous cast sheet are noted.

**The Effect of Ingot Weight on the Quality of Structural Steels.** M. I. Kolosov, I. Ya. Aizenshtok, A. I. Komissarov, G. E. Mysina, and M. S. Povolotskaya. (*Stal'*, 1958, (5), 411–414). The increase of ingot weight in relation to 18% Cr–Ni–V steel from 1·8 to 2·65 and to 4·5 t is necessary as macrostructure has deteriorated owing to the development of axial cracks which do not seal up on rolling. The effect of weight on quality in Cr-Ni and Cr–Mn steels was examined. Information on prosity which welds up or does not weld up on rolling is included.

**Studies on the Solidification and Segregation of Larger Steel Ingots. I. Direct Measurement of Solidification Rate by Bar-Test.** H. Morikawa, S. Onodera, and Y. Arakida. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 9–14). [In Japanese]. Solidification data are presented, based on measurements of over 40 killed, concave, octagonal ingots of weights varying between 3 and 75 t. The effects of ingot size, composition, bottom shape and change of temperature in the feeder head are discussed.

## PRODUCTION OF FERRO-ALLOYS

**Pittsburgh Coke and Chemical Company Now Markets Ferromanganese.** (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 385–388). The conversion of a 22 ft hearth dia. blast furnace to make ferromanganese is described; particular reference being made to the new gas cleaning plant. The importance of ferromanganese in steelmaking is discussed.

**Experimental Electric Smelting of Manganese Ores: II. [Production of Iron, Silicospiegeleisen and Portland Cement from a Low-Grade Ore.** R. A. Campbell, G. N. Banks and R. R. Rogers. (*Canad. Min. Met. Bull.*, 1958, **51**, May, 288–293). A two-stage process giving pig-iron and silicospiegeleisen successively is described and the process is regarded as economic. The best period gave a 18·8% iron, 10·03% Si, 2·48% C and 67·8% Fe product and iron with 0·17% Mn, 1·03% Cr, 0·083% S and 0·026% P.

**Chromium and Ferrochrome for Special Steels.** C. Dingeon. (*Rev. Mét.*, 1958, **55**, Jan., 1–8). After describing the main sources of Cr an outline is given of the metallurgy of the production of high, medium and low ferrochromes, and of Cr metal. An indication is given of the impurities normally present. The production of low-carbon ferrochrome is described in some detail.—L. D. H.

**Industrial Grades of Ferro-Nickel and their Principal Uses.** J. A. Ternisien. (*Mét. Constr. Mécan.*, 1957, **89**, Oct., 817–827; Nov., 917–925, 940, 953). The different varieties of Fe-Ni are considered and the elastic, magnetic and electrical properties are discussed. Compositions of iron–nickel alloys suitable for a variety of purposes are presented in tabular form.—B. G. B.

## FOUNDRY PRACTICE

**The Foundry Technique in the German Democratic Republic.** A. Krenkel and H. Grosser. (*Iron Steel Rev.*, 1958, **1**, Apr., 23–25). Work by the Central Institute for Foundry Technique, Leipzig, is outlined. A list of producers of foundry equipment and their machines is included.

**Foundries in the East Midlands.** (*Foundry Trade J.*, 1958, **104**, Apr. 3, 385–395; Apr. 10, 419–427; Apr. 17, 461–464). Brief illustrated accounts of foundries to be visited during the Buxton Meeting of the Inst. Brit. Found. are given.

**The Ford Thames Foundry, Dagenham.** (*Engineering*, 1958, **185**, June 6, 732–733). Illustrated and with a plan.

**Ford Motor Company's Thames Foundry at Dagenham.** (*Engineer*, 1958, **205**, June 6, 852–853). An illustrated description. (Also *Machinery*, 1958, **92**, May 30, 1297–1305).

**The New Ford Thames Foundry.** (*Machinery*, 1958, **92**, June 6, 1351–1354). Core sand mixing, cooling, flash-grinding and fettling operations are described.

**New Thames Foundry.** Ford Motor Co. (*Found. Trade J.*, 1958, **104**, May 29, 627–663). A full illustrated account of the origin and construction of the Dagenham plant with a list of contractors and suppliers of equipment.

**The Ford "Thames" Foundry.** (*Auto. Eng.*, 1958, **48**, June, 233–246). A fully illustrated account.

**Mechanisation and Automation in the Foundry.** K. W. Pavlowitz. (*Maschinenwelt Elek.*, 1957, **12**, July, 199–202). The author discusses the mechanization and automation of foundry processes and equipment, with particular reference to German practice.

**Wholly Rammed Cupola Linings.** F. Sandford. (*Gjuteriet*, 1958, **48**, Feb., 25–27). Melting tests are reported. The cupola was in intermittent use for 8–10 days without repair. Ganister should be low in moisture and the linings should be carefully dried to prevent cracking. The consumption of ganister is 20–25 Kg/t iron melted. Profiles are shown.

**Construction and Operation of Modern Hot-Blast Cupola Plants.** S. Tunder and A. Esser. (*Giesserei*, 1958, **45**, Feb. 13, 92–96). Modern technical developments in the hot-blast cupola are described. Problems connected with drawing off the top gas, combustion of the CO and utilization of the heat of the waste gases are discussed, and the article concludes with an outline of the development and applications of the hot-blast basic cupola.

**The Controlled-Slag Hot-Blast Cupola.** D. Fleming. (*Mod. Castings*, 1958, **33**, April, 47–58). The construction of 2 full-scale hot blast cupolas is described together with the results of trials. Modifications to the theory of the hot blast cupola are suggested and the advantage of still hotter blast is stressed.—A. G.

**MBC Performance: U.K. Hot-Blast Cupola Operating Experience.** A. R. Parkes. (*Foundry Trade J.*, 1958, **104**, Apr. 24, 485–490). The Metallurgical Blast Cupola developed at Liège is now installed at an English Foundry and an illustrated account of its working is presented.

**Methods of Melting Iron in Foundries, Cupolas and High Frequency Furnaces.** J. G. Robin. (*Mét. Constr. Mécan.*, 1956, **88**, Dec., 1011–1015). A survey is made of the range of techniques employed for melting iron under foundry conditions. Cold and hot blast cupolas are compared and the technical and economic advantages of the latter are explained. Industrial h.f. melting furnaces are considered and details of their advantages and operating costs are given. The selection of a melting technique for a foundry is discussed.—B. G. B.

**Mains Frequency Induction Melting of High Speed Steels.** (*Metallurgia*, 1958, **57**, March, 198). The installation of a Birlec furnace by the Inca Steel Co. is reported. The turbulence of the molten metals does not increase inclusion content.—A. G.

**Mode of Operation and Lining of the Graphite Electrode Melting Furnace.** K. Wagner. (*Giesserei*, 1958, **45**, Feb. 13, 100–103). This is a resistance-heated rotary furnace, in which the element is a graphite rod, and A.C. current is provided at 15–75 V and 3000–6000 A. The capacity of the furnace is 300 kg; the monolithic lining is corundum, backed with insulating brick.—L. D. H.

**Use of the Electric Induction Furnace at Mains Frequency in Italian Foundries.** M. E. Calamari. (*J. Four Elect.*, 1957, **62**, Nov.-Dec., 211–216). After outlining the background to the development in the use of electric induction furnaces in Italy, examples of their application to several types of foundry and product are given.—L. D. H.

**New Methods for Bath Production at Greenford.** (*Found. Trade J.*, 1958, **104**, May 8, 539–546). A description of the new foundry of the British Bath Co.

**Bilston Foundries' New Bath Plant.** (*Foundry Trade J.*, 1958, **104**, May 1, 511–518). A plan and illustrated description are given.

**Cast Iron for Glass Moulds.** R. Barton. (*B.C.I.R.A.J. Res. Dev.*, 1958, **7**, Feb., 146–156). The properties required for glass moulds and the effects of composition and structure are set out. A specification for glass mould iron is advanced. Mould faces should be chill cast to prevent graphite flakes from reaching the working surface where they promote rapid breakdown. Other problems of the glass moulding industry are considered.

**Researches on the Shrinkage of Grey Cast Iron.** (*Fonderia*, 1958, **7**, Apr., 166–168). A brief account is given of the causes and mechanics of shrinkage in grey cast irons. Means of reducing shrinkage are discussed and the effects of certain elements on shrinkage are considered. The effects of temperature rate of cooling and gas content are also discussed.—M. D. J. B.

**Magnesium Content and Graphite Forms in Cast Iron.** J. F. Ellis and C. K. Donoho. (*Mod. Castings*, 1958, **33**, May, 105–111). The effect of increasing Mg in three different base irons on tensile properties and graphite structures has been determined. Results are discussed and an extension of the standard system of graphite classification is suggested.

**Nodular Graphite in Grey Iron.** R. Bartschinger. (*Schweizer Archiv.*, 1949, **15**, Mar., 75–84). A general review of structure and mode of formation is given. The effects of Ce, Mg, Co and Mischmetal are discussed and the physical and mechanical properties of nodular iron are given.

**Use of Alloys in the Manufacture of Cast Iron.** T. Andresen. (*Second National Congress of the Iron and Steel Industry*, [Mexico],

1957, 143–152). Mn, Cr, Zr, SMZ, and the ferro-alloys are discussed, together with methods of making the additions to the melt. Nodular irons are described. **The Design of Castings.** M. Lizcano (261–265). Foundry difficulties are discussed and examples given of defects arising from (a) design and (b) production errors. **The Veracruz Foundry, a Mexican Steelplant Achievement.** F. Gonzalez (207–220). Technical details of the furnace plant of the Fundidora Veracruzana Company are supplied; the plant includes an O.H. furnace, two hot blast cupolas and two side-blown convertors. **Inspection and Quality Control of Cast Steel.** A. Robinat (367–370). Points to be safeguarded in the production of castings, from the pattern to the heat-treated product, are discussed.

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**Vacuum Steel Grows Up.** J. H. Stoll. (*Prod. Eng.*, 1958, **29**, May 26, 70–71). A brief note on developments at the Bethlehem Steel Co. plant.

**[Vacuum Treatment of Acid Bessemer Metal].** A. D. Kutsenko. (*Stal'*, 1958, (5), 415). Killed and rimming rail steels were examined for reduction of $N_2$ content. The ladle was placed in a vacuum chamber for 14–15 min. $H_2$ was reduced by 53·8% in rimming and 48·7% in killed steel, but $N_2$ by only 10–20%. C also fell by 30–45%, Mn by 15–25%, P and S were unchanged in rimming steel, in killed steel the changes were negligible.—B. S.

**On Vacuum Arc Melting and Experience with New Equipment.** R. Kieffer and W. Wirth. (*Data on High Vacuum Technology and the Physics of Thin Layers.* (*Wissenschaftliche Verlagsges. m.b.H. Stuttgart*, 1957, 178–183). Melting of refractory and reactive metals is discussed and a medium-size vacuum arc melting unit installed at Reutte/Tyrol is described.

**Vacuum Deoxidation and Desulphurization of Transformer Steel.** A. M. Samarin. (*"Use of the Vacuum in Steel Melting Processes" Chapter* 1, 1957, 3–14). Recommendations for the melting and furnace treatment of transformer steel in the vacuum furnace are made. Reduction of pressure to 1 mm increases deoxidizing power of the carbon by ~ 100 times. Sulphur is also removed, the completeness depending upon reduction of oxygen content.

**Review and Appraisal of Vacuum Melting.** E. A. Loria. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 379–384, 388). A critical review of vacuum arc and vacuum induction melting is presented. The effect of vacuum melting on the properties of a number of alloys is discussed.—B. G. B.

**Vacuum Melted Metals, Steel, Titanium and Zirconium in Production.** (*Metallurgia*, 1958, **57**, March, 139–142). After a brief review of the research and development facilities of William Jessop's, the production and properties of vacuum melted steels and titanium and zirconium alloys are described.

**Influence of Vacuum Melting on the Properties of Various Materials.** W. F. Moore and A. J. Kiesler. (*Foundry Trade J.*, 1958, **104**, June 19, 741–745). A short section on steels is included, and the improvement in impact properties is shown.

**[Effect of Vacuum Treatment on the Properties of Hot Rolled Transformer Steel.]** G. N. Shubin. (*Stal'*, 1958 (5), 427). Short time vacuum treatment of transformer steel effected no improvement but treatment for 20 min. greatly reduced specific losses especially in ¼ mm sheet. This reduced $H_2$ from 5–6 to 4–4·5 c.c./100 g. and oxygen and oxides were reduced 25–30%.—B. S.

## REHEATING FURNACES AND SOAKING PITS

**Reserves of Productivity of Soaking Pits.** L. V. Ilovaiskii. (*Stal'*, 1958, (6), 537–541). Improved organization of stripping, feeding and transferring of ingots at high temperature before charging into the pits is described. Most of the pits were planned during the first 5-year plans and were based on 20% cold charging. The productivity reserves were used as blooming mill capacity, increased by reducing the extent of cold charging. It is now down to 4–6% so the reserves have practically disappeared.—B. S.

**New Developments in Furnace Construction for Drop Forging.** E. Pflaume. (**Fertigungstechnik*, 1957, **7**, Feb., 63–64). The rotary hearth furnace and the use of oil firing are discussed.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Furnace Atmospheres from Liquids.** I. L. S. Golding. (*Metallurgia*, 1958, **57**, Jan., 23–25). Results of an investigation into the influence of liquid stock composition, temperature and catalyst on the atmosphere produced are reported. A method of varying carbon potential by the addition of hydrocarbon is described.—A. G.

**The Heat Treatment of Small Parts—Shock Furnaces.** (*Mét. Constr. Mécan.*, 1957, **89**, Nov., 959–963). The difficulties associated with the heat treatment of small parts are examined and the principle and mechanism of the shock furnace are explained. The determination of the operating cycle is discussed and illustrations of commercial equipment are reproduced.—B. G. B.

**Morphological and Phase Changes During Quench-ageing of Ferrite Containing Carbon and Nitrogen.** G. Lagerberg and B. S. Lement. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 33, pp. 33). The following two-stage reactions were found to occur during quench-ageing of alloys: ferrite supersaturated with carbon (0·016%) → $\varepsilon$-carbide → cementite; ferrite supersaturated with nitrogen (0·084%) → $\alpha''$-nitride → $\gamma'$-nitride; ferrite supersaturated with both carbon and nitrogen → → $\varepsilon$-carbonitride → cementite. Films formed in initial stages at ferritic sub-boundaries were probably due to segregation of solute atoms; platelets were eventually formed.—E. E. W.

**Heat Treatment of Carbon Rimming Steel of Structural Quality.** M. V. Pridantsev, A. A. Bat', L. I. Gladshtein and Kh. Sh. Levinzon. (*Stal'*, 1958, (5), 449–456). A steel with 0·14–0·19% C, 0·47–0·54% Mn, trace Si, 0·03–0·02% Cr, 0·03–0·04% Ni, 0·24–0·25% Cu, 0·025–0·017% P and 0·044–0·033% S was tested by quenching without tempering and quenching with high temper. The first improved the properties so that less steel could be used for a given construction; 12–40 mm plate had a tensile strength of at least 30 kg/mm², and impact strength after ageing of 4–6 kg/cm² while the cold brittleness threshold was not higher than − 60° C.—B. S.

## FORGING, STAMPING, DRAWING AND PRESSING

**The Construction of Solid Forged Steel Boiler Drums.** W. A. Hawkins. (*Mét. Constr. Mécan.*, 1956, **88**, Dec., 1017–1023, 1033). A detailed, illustrated description of the techniques used at the River Don works of the English Steel Corporation for the construction of forged boiler drums is given.—B. G. B.

**Standardised Tolerances for Steel Parts Produced on Horizontal Forging Machines.** J. Husson and H. Liotard. (*Mét. Constr. Mécan.* 1957, **89**, Nov., 927–933). The operation of this machine is first described and the range of shapes which can be made is explained. The dimensional variations which occur on repeat forgings are examined and a new French standard NF105 to cover the

machining allowances corresponding to these variations is presented.—B. G. B.

**Modern Technology of the Drop Forging of Crankshafts.** J. Šedivec. (*Maschinenwelt Elek.*, 1957, **12**, Dec., 361–364). A description is given of an improved method of drop forging a crankshaft, the operation being more economical and producing a more uniform structure.—L. D. H.

**How to Determine Forging and Finishing Periods.** H. Haller. (**Werkstatt und Betrieb*, 1957, **90**, Apr. 227–232). Calculations of the work done in drawing and pressing, and hammer and press capacity are made and a numerical example is worked out giving a standard time for the production of rectangular bars.

**The Present Position of Cold-Heading, Cold Pressing and Flow Pressing in the Manufacture of Bolts.** H. Heine. (**Werkstattstechnik u. Maschinenbau*, 1950, **40**, (6), 214–220).

**Thin-Walled Bushings of Bimetallic Strip. (Steel–Aluminium Alloys).** L. Yu. Pruzhanskii. (*Vestnik Mashin.* 1958, (3), 36–37). Experiments show that annealing at 490° for 45 min. ensures production of good shapes in stamping. For a further increase in plasticity and a reduction in hardness, heating to a much higher temperature is required. In such cases a twin-metal strip with an intermediate layer of metal or alloy which would permit such heating, should be used.—L. H.

**Mechanical Descaling and Drawing of Mild Steel Rod.** L. Marsden. (*Wire Wire Prod.*, 1958, **33**, Mar., 298–302, 343–344). Based on experience at J. & A. Binns Ltd., Halifax, the author outlines features of mechanical descaling equipment and layout, followed by a description of the methods of preparing rod, and of drawing, with particular emphasis on lubrication.—J. G. W.

**Rotary Piercing.** F. Wiesner. (**Hutn. Listy*, 1955, **10**, (3), 130–139).

**Savings in Material and Production Costs by Flow Turning.** J. Genis and W. Mallindine. (*Machinery*, 1958, **93**, July 9, 87–92). The rotary extrusion process of the Ford Motor Co., Aircraft Engine Division is described. Stainless steel and other materials are shaped by a rolling process.

**The Theory of Extrusion.** J. F. W. Bishop. (*Met. Rev.*, 1957, **2**, (8), 361–390). (29 refs.).

## ROLLING MILL PRACTICE

**Contribution to the Study of Rolling Mill Installations. 2. Rolling Mill Installations.** G. Grenier. (*Echo Mines*, 1957, July, 409–410; Aug., 461–464; Sept., 521–523; Oct., 584–588; Nov., 653–657; Dec., 721–722; 1958, Jan. 31–33; Feb., 99–102; Mar., 159–160; Apr. 227–229; May, 293–295; June, 365–367). **1. General.** An historical review is given, 1880–1910, on the development of the continuous mill. **2. Intermediate Product Mill Trains.** Historical, with accounts of the periods, 1880–1900, 1900–1910, 1910–1920, 1920–1935, present day, with accounts of various large installations. **3. Universal Mills for Small Beams with Wide Flanges.** The rolling of rails and similar sections is described. **4. Mill Trains for Rails and Profiles; 5. Merchant Mills for Iron and Steel.** With historical introduction; **6. Rod and Wire Mills; 7 Plate Mills; 8. Conclusions.**

**Report of the Committee on Re-rolling Mills, Electric Furnaces and Steel Foundries: A Review.** (*Iron Steel Rev.*, 1957, **1**, Dec., 27–30). The committee was set up by the Indian government and its report is considered. Accurate estimates were not obtained and the report does not appear to go far enough in answering the problems of the industry.

**Energy Requirements and Electrical Equipment for Hot-Rolling Mills.** R. E. Marrs. (*First National Congress Iron and Steel Industry* [*Mexico*], 1955, 187–211).

**Calculating the Pressure of Metal on the Rolls.** Yu. M. Chizhikov. (*Stal'*, 1958, (5), 428–433). Neither Ekelund's nor Tselikov's formula correctly represents actual rolling conditions and the development of a formula to determine pressure against the rolls is regarded as one of the main problems of rolling technology. The above formulae and many measurements are given.—R. S.

**Present State of the Theory of Metal Pressure on Rolls in Longitudinal Rolling.** A. I. Tselikov. (*Stal'*, 1958, (51, 434–441). The value of the Tselikov formula depends mainly on correct determination of the influence of external friction and on taking into account the influence of the width of the strip and the changes in resistance to deformation in the "arc of bite." The effects of the above are not sufficiently precisely determined in the formula and some suggestions for improvement are made.—R. S.

**Programme-controlled Roughing in an American Steel Mill.** L. C. Sowell. (*Autom. Prog.*, 1958, **3**, June, 212–213, 229). An account of the Jones and Laughlin Corp. Aliquippa hot strip mill punched card reversing rougher control is given.

**Process of Hot Rolling and Cold Drawing of High Sulphur Steels.** P. G. Quintanilla. (*First National Congress of the Iron and Steel Industry*, [*Mexico*], 1955, 213–230). Details are given of the rolling of free-cutting steels; particular attention is given to roll passes and their design. The cold drawing process is also described. **Rolls for Modern Rolling Plant. Sixth Committee. Various Topics.** F. H. Allison, jun., (245–261). The manufacture of cast iron, alloy cast iron and cast steel rolls is described. Typical uses are also given. **Modern Methods of Producing Iron and Steel Rolls.** J. M. Dugan (263–282). A pictorial account of roll manufacture is given.

**Rolling of "Endless" Billets which have been Welded Together.** A. E. Lendl and R. Preissler. (*V.D.I.Z.*, 1958, **100**, Feb. 11, 165–171). Trials have shown that it is possible to roll economically billets which have been butt welded together into a much longer strand. Welding can be carried out in various types of mill, and the metallurgical structure of the joint is quite satisfactory. Details of the application of the process to killed and rimming steels are given.—L. D. H.

**Fundamental Problems of the Heterogeneous Deformation Induced by Rolling.** L. Hellebrand. (*Sborník Ostravě*, 1957, **3**, (2), 41–49). [In Czech]. Tafel's law and other proposals for the evaluation of mean elongation of shapes on rolling are critically surveyed and shown to be inadequate, or incompatible with the known requirement of the invariance of volume in plastic deformation. A formula derived by the author is shown to be free from these inconsistencies.

**On the Variation of the Ductility with the Rolling Direction and the Location of the Sample in the Plate.** B. Otta and J. Teindl. (*Sborník Ostravě*, 1957, **3**, (2), 13–22). [In Czech]. Bend tests on samples cut from various positions of 0·02 and 0·014 in. thick 0·01% C and 4·3% Si transformer sheet showed considerable variations of ductility with sample position in the sheet. The effect is ascribed to differences in the preferential orientation of grains over the area of the sheet. No significant differences in the ductility of O.H. and converter steels of similar composition were detected.—P. E.

**Stationary Convertors for Feeding Rolling Mill Trains.** E. Azaceta. (*Dyna*, 1957, **32**, Dec., 744–758). [In Spanish]. The theory and practice of electricity supply to rolling mill motors is discussed, and it is concluded that feeding from rectifiers is advantageous both in use and for power requirements.—P. S.

**The Manufacture of Two-Patterns for Rolling Mill Housings.** F. Lamm. (*Giesserei*, 1957, **44**, Aug. 29, 520–522). The simultaneous fabrication of two patterns for rolling mill housings, each final casting weighing about 100 tons is described. The pattern design and construction is illustrated in seven diagrams and photographs. A cost comparison, including a numerical analysis as an example, shows the method described to have appreciable advantages over others.—R. J. W.

**Increasing the Load-Bearing Capacity of Plate Mill Housings.** B. A. Morozov, L. T. Timoshuk and B. I. Taratorin. (*Stal'*, 1957, (12), 1107–1110). The weakest part of a plate mill housing is the bridge, especially when it contains holes for the screw-down gear. To improve load bearing capacity, (*a*) the bearing surface of the nut of the adjusting screw is transferred to the lower surface of the bridge or to the zone of compression stresses; (*b*) the radii of the points of transition to the highly stressed zones are increased or, if this is not possible, these transition zones should be shot-peened or roller hardened.

**New Mill Will Roll Tough Steels.** (*Steel*, 1957, **141**, Dec. 2, 99–100). The use of a 32 in. cogging mill at Latrobe Steel Co. is described. It replaces hammer and press forging for superalloys and high-speed steels. One special feature is the use of diamond grooved rolls which distribute the hot deformation more uniformly than flat rolls, particularly in the centre of the ingot.—D. L. C. P.

**The Rolling of Stainless Steel Ingots.** J. Chvojka. (*Hutník*, 1957, **7**, (11), 370–374). [In Czech]. Experiments on the rolling of 18/8 type steels containing about 0·3% Ti and 0·1% Cu lead to the following findings: (*a*) To obtain good surfaces it is necessary to use high pouring rates, to pour in an inert atmosphere, preferably using bottom pouring Rectangular ingots are preferable to octagonal ones. (*b*) One of the main causes of tear formation is the presence of alpha-phase. (*c*) More alpha-phase exists in the interior than near the surface of ingots. (*d*) The amount of alpha-phase may be determined by magnetic methods or by calculation using an empirical formula. (*e*) It would be best to reduce the Cr content to 15–18%, in which case a pure austenitic structure results. (*f*) If the ferrite content exceeds about 10% there is considerable danger of tear formation on heating above about 1200° C; in purely austenitic steels this temperature can be exceeded without danger to the steel. (*g*) The optimum amount and grain size of ferrite results on austenitizing at about 1200° C for 2–4 h. (*h*) The rate of heating above 900° C. can be up to 120° C/h. (*i*) The first passes on rolling should be smoothing passes; it is necessary to turn the billets over several times.—P. F.

**The Development of Optimum Ingot Sizes for Flat Rolled Products.** J. G. Sibakin. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 41–75, discussion 76–79). Calculations are presented for the interrelationships of the units of a hot strip mill. Finishing temperatures, coil length, rolling time, motor loads, entry temperatures and ingot size are related. The sequence of steps for establishing optimum practice is given.

**Carbon Steel: Plates; Structural Sections; Rolled Floor Plates; Steel Sheet Piling.** (*A.I.S.I. Steel Prod. Man.*, 1957, Dec., pp. 65.)

**The Development of Rolls and Profiles for Plates of Endless Tracks of Caterpillar Vehicles.** J. Dobeš and M. Žídek. (*Hutník*, 1957, **7**, (11), 368–370). [In Czech]. The manufacture and design of tractor belt plates from sections is described.—P. F.

**Production of Universal Beams: Modern Rolling Technique.** S. Barlow. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 24, 217–220). The mill at Lackenby Works of Dorman Long & Co. is described and the stages in beam rolling are shown.

**A Modern German Plate Mill.** W. Hilterhaus. (*Iron Coal Trades Rev.*, 1958, **176**, Feb. 7, 329–332; from *Klepzig Fachberichte*, 1957, (1)). An account of the 165-in four-high mill of Ruhrstahl A.G., Hattingen and the use of vertical edging rolls.

**Chemical and Structural Heterogeneity of Thick Sheet Rolled from Rimming Steels.** M. Žídek and J. Choleva. (*Hutník*, 1957, **7**, (9), 298–305). [In Czech]. A report is given of a detailed study of ingot heterogeneity occurring in steels with 0·1–0·25% C content. Compliance of the metal in various zones in the ingot with weldability standards was examined. The researches facilitate the most economical way of sectioning the ingots.

**Mechanisation of Rolling Mill Alleys for Thin Hot-Rolled Sheet.** E. Bohuš. (*Hutník*, 1957, **7**, (12), 404–408). [In Czech]. The

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## VACUUM METALLURGY

**Effect of Vacuum Melting on Steel Quality.** Ya. M. Bokshitskii, A. V. Emyashev, A. M. Zubko and M. M. Filippycheva. (*Stal'*, 1958 (6), 520–525). The quality of 2% Cr–4% Ni–0·14% C steel was improved especially in impact properties. Heats produced at $10^{-4}$ mm contained 0·002% N instead of 0·01%, oxygen content at pressures down to $10^{-3}$ mm was about one-fifth that present without a vacuum. Inclusions were reduced to about one-tenth and impact strength increased 40%.—R. S.

**Vacuum Steel Grows Up.** J. H. Stoll. (*Prod. Eng.*, 1958, **29**, May 26, 70–71). A brief note on developments at the Bethlehem Steel Co. plant.

**[Vacuum Treatment of Acid Bessemer Metal].** A. D. Kutsenko. (*Stal'*, 1958, (5), 415). Killed and rimming rail steels were examined for reduction of $N_2$ content. The ladle was placed in a vacuum chamber for 14–15 min. $H_2$ was reduced by 53·8% in rimming and 48·7% in killed steel, but $N_2$ by only 10–20%. C also fell by 30–45%, Mn by 15–25%, P and S were unchanged in rimming steel, in killed steel the changes were negligible.—R. S.

**On Vacuum Arc Melting and Experience with New Equipment.** R. Kieffer and W. Wirth. (*Data on High Vacuum Technology and the Physics of Thin Layers.* (*Wissenschaftliche Verlagsges. m.b.H. Stuttgart*, 1957, 178–183). Melting of refractory and reactive metals is discussed and a medium-size vacuum arc melting unit installed at Reutte/Tyrol is described.

**Vacuum Deoxidation and Desulphurization of Transformer Steel.** A. M. Samarin. (*"Use of the Vacuum in Steel Melting Processes" Chapter* 1, 1957, 3–14). Recommendations for the melting and furnace treatment of transformer steel in the vacuum furnace are made. Reduction of pressure to 1 mm increases deoxidizing power of the carbon by ~ 100 times. Sulphur is also removed, the completeness depending upon reduction of oxygen content.

**Review and Appraisal of Vacuum Melting.** E. A. Loria. (*Blast Furn. Steel Plant*, 1958, **46**, Apr., 379–384, 388). A critical review of vacuum arc and vacuum induction melting is presented. The effect of vacuum melting on the properties of a number of alloys is discussed.—B. G. B.

**Vacuum Melted Metals, Steel, Titanium and Zirconium in Production.** (*Metallurgia*, 1958, **57**, March, 139–142). After a brief review of the research and development facilities of William Jessop's, the production and properties of vacuum inelted steels and titanium and zirconium alloys are described.

**Influence of Vacuum Melting on the Properties of Various Materials.** W. F. Moore and A. J. Kiesler. (*Foundry Trade J.*, 1958, **104**, June 19, 741–745). A short section on steels is included, and the improvement in impact properties is shown.

**[Effect of Vacuum Treatment on the Properties of Hot Rolled Transformer Steel.]** G. N. Shubin. (*Stal'*, 1958 (5), 427). Short time vacuum treatment of transformer steel effected no improvement but treatment for 20 min. greatly reduced specific losses especially in ½ mm sheet. This reduced $H_2$ from 5–6 to 4–4·5 c.c./100 g. and oxygen and oxides were reduced 25–30%.—R. S.

## REHEATING FURNACES AND SOAKING PITS

**Reserves of Productivity of Soaking Pits.** L. V. Ilovaiskii. (*Stal'*, 1958, (6), 537–541). Improved organization of stripping, feeding and transferring of ingots at high temperature before charging into the pits is described. Most of the pits were planned during the first 5-year plans and were based on 20% cold charging. The productivity reserves were used as blooming mill capacity, increased by reducing the extent of cold charging. It is now down to 4–6% so the reserves have practically disappeared.—R. S.

**New Developments in Furnace Construction for Drop Forging.** E. Pflaume. (**Fertigungstechnik*, 1957, **7**, Feb., 63–64). The rotary hearth furnace and the use of oil firing are discussed.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Furnace Atmospheres from Liquids.** I. L. S. Golding. (*Metallurgia*, 1958, **57**, Jan., 23–25). Results of an investigation into the influence of liquid stock composition, temperature and catalyst on the atmosphere produced are reported. A method of varying carbon potential by the addition of hydrocarbon is described.—A. G.

**The Heat Treatment of Small Parts—Shock Furnaces.** (*Mét. Constr. Mécan.*, 1957, **89**, Nov., 959–963). The difficulties associated with the heat treatment of small parts are examined and the principle and mechanism of the shock furnace are explained. The determination of the operating cycle is discussed and illustrations of commercial equipment are reproduced.—B. G. B.

**Morphological and Phase Changes During Quench-ageing of Ferrite Containing Carbon and Nitrogen.** G. Lagerberg and B. S. Lement. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 33, pp. 33). The following two-stage reactions were found to occur during quench-ageing of alloys: ferrite supersaturated with carbon (0·016%) → $\alpha$ –carbide → cementite; ferrite supersaturated with nitrogen (0·084%) → $\alpha''$–nitride → $\gamma'$–nitride; ferrite supersaturated with both carbon and nitrogen → → $\epsilon$-carbonitride → cementite. Films formed in initial stages at ferritic sub-boundaries were probably due to segregation of solute atoms; platelets were eventually formed.—E. E. W.

**Heat Treatment of Carbon Rimming Steel of Structural Quality.** M. V. Pridantsev, A. A. Bat', L. I. Gladshtein and Kh. Sh. Levinzon. (*Stal'*, 1958, (5), 449–456). A steel with 0·14–0·19% C, 0·47–0·54% Mn, trace Si, 0·03–0·02% Cr, 0·03–0·04% Ni, 0·24–0·25% Cu, 0·025–0·017% P and 0·044–0·033% S was tested by quenching without tempering and quenching with high temper. The first improved the properties so that less steel could be used for a given construction; 12–40 mm plate had a tensile strength of at least 30 kg/mm², and impact strength after ageing of 4–6 kg/cm² while the cold brittleness threshold was not higher than — 60° C.—R. S.

## FORGING, STAMPING, DRAWING AND PRESSING

**The Construction of Solid Forged Steel Boiler Drums.** W. A. Hawkins. (*Mét. Constr. Mécan.*, 1956, **88**, Dec., 1017–1023, 1033). A detailed, illustrated description of the techniques used at the River Don works of the English Steel Corporation for the construction of forged boiler drums is given.—B. G. B.

**Standardised Tolerances for Steel Parts Produced on Horizontal Forging Machines.** J. Husson and H. Liotard. (*Mét. Constr. Mécan.* 1957, **89**, Nov., 927–933). The operation of this machine is first described and the range of shapes which can be made is explained. The dimensional variations which occur on repeat forgings are examined and a new French standard NF105 to cover the

machining allowances corresponding to these variations is presented.—B. G. B.

**Modern Technology of the Drop Forging of Crankshafts.** J. Sedivec. (*Maschinenwelt Elek.*, 1957, **12**, Dec., 361–364). A description is given of an improved method of drop forging a crankshaft, the operation being more economical and producing a more uniform structure.—L. D. H.

**How to Determine Forging and Finishing Periods.** H. Haller. (**Werkstatt und Betrieb*, 1957, **90**, Apr. 227–232). Calculations of the work done in drawing and pressing, and hammer and press capacity are made and a numerical example is worked out giving a standard time for the production of rectangular bars.

**The Present Position of Cold-Heading, Cold Pressing and Flow Pressing in the Manufacture of Bolts.** H. Heine. (**Werkstattstechnik u. Maschinenbau*, 1950, **40**, (6), 214–220).

**Thin-Walled Bushings of Bimetallic Strip. (Steel–Aluminium Alloys).** L. Yu. Pruzhanskii. (*Vestnik Mashin.* 1958, (3), 36–37). Experiments show that annealing at 490° for 45 min. ensures production of good shapes in stamping. For a further increase in plasticity and a reduction in hardness, heating to a much higher temperature is required. In such cases a twin-metal strip with an intermediate layer of metal or alloy which would permit such heating, should be used.—L. H.

**Mechanical Descaling and Drawing of Mild Steel Rod.** L. Marsden. (*Wire Wire Prod.*, 1958, **33**, Mar., 298–302, 343–344). Based on experience at J. & A. Binns Ltd., Halifax, the author outlines features of mechanical descaling equipment and layout, followed by a description of the methods of preparing rod, and of drawing, with particular emphasis on lubrication.—J. G. W.

**Rotary Piercing.** F. Wiesner. (**Hutn. Listy*, 1955, **10**, (3), 130–139).

**Savings in Material and Production Costs by Flow Turning.** J. Genis and W. Mallindine. (*Machinery*, 1958, **93**, July 9, 87–92). The rotary extrusion process of the Ford Motor Co., Aircraft Engine Division is described. Stainless steel and other materials are shaped by a rolling process.

**The Theory of Extrusion.** J. F. W. Bishop. (*Met. Rev.*, 1957, **2**, (8), 361–390). (29 refs.).

## ROLLING MILL PRACTICE

**Contribution to the Study of Rolling Mill Installations. 2. Rolling Mill Installations.** G. Grenier. (*Echo Mines*, 1957, July, 409–410; Aug., 461–464; Sept., 521–523; Oct., 584–588; Nov., 653–657; Dec., 721–722; 1958, Jan. 31–33; Feb., 99–102; Mar., 159–160; Apr. 227–229; May, 293–295; June, 365–367). **1. General.** An historical review is given, 1880–1910, on the development of the continuous mill. **2. Intermediate Product Mill Trains.** Historical, with accounts of the periods, 1880–1900, 1900–1910, 1910–1920, 1920–1935, present day, with accounts of various large installations. **3. Universal Mills for Small Beams with Wide Flanges.** The rolling of rails and similar sections is described. **4. Mill Trains for Rails and Profiles; 5. Merchant Mills for Iron and Steel.** With historical introduction; **6. Rod and Wire Mills; 7 Plate Mills; 8. Conclusions.**

**Report of the Committee on Re-rolling Mills, Electric Furnaces and Steel Foundries: A Review.** (*Iron Steel Rev.*, 1957, **1**, Dec., 27–30). The committee was set up by the Indian government and its report is considered. Accurate estimates were not obtained and the report does not appear to go far enough in answering the problems of the industry.

**Energy Requirements and Electrical Equipment for Hot-Rolling Mills.** R. E. Marrs. (*First National Congress Iron and Steel Industry* [*Mexico*], 1955, 187–211).

**Calculating the Pressure of Metal on the Rolls.** Yu. M. Chizhikov. (*Stal'*, 1958, (5), 428–433). Neither Ekelund's nor Tselikov's formula correctly represents actual rolling conditions and the development of a formula to determine pressure against the rolls is regarded as one of the main problems of rolling technology. The above formulae and many measurements are given.—R. S.

**Present State of the Theory of Metal Pressure on Rolls in Longitudinal Rolling.** A. I. Tselikov. (*Stal'*, 1958, (51, 434–441). The value of the Tselikov formula depends mainly on correct determination of the influence of external friction and on taking into account the influence of the width of the strip and the changes in resistance to deformation in the "arc of bite." The effects of the above are not sufficiently precisely determined in the formula and some suggestions for improvement are made.—R. S.

**Programme-controlled Roughing in an American Steel Mill.** L. C. Sowell. (*Autom. Prog.*, 1958, **3**, June, 212–213, 229). An account of the Jones and Laughlin Corp. Aliquippa hot strip mill punched card reversing rougher control is given.

**Process of Hot Rolling and Cold Drawing of High Sulphur Steels.** P. G. Quintanilla. (*First National Congress of the Iron and Steel Industry*, [*Mexico*], 1955, 213–230). Details are given of the rolling of free-cutting steels; particular attention is given to roll passes and their design. The cold drawing process is also described. **Rolls for Modern Rolling Plant. Sixth Committee. Various Topics.** F. H. Allison, jun., (245–261). The manufacture of cast iron, alloy cast iron and cast steel rolls is described. Typical uses are also given. **Modern Methods of Producing Iron and Steel Rolls.** J. M. Dugan (263–282). A pictorial account of roll manufacture is given.

**Rolling of "Endless" Billets which have been Welded Together.** A. E. Lendl and R. Preissler. (*V.D.I.Z.*, 1958, **100**, Feb. 11, 165–171). Trials have shown that it is possible to roll economically billets which have been butt welded together into a much longer strand. Welding can be carried out in various types of mill, and the metallurgical structure of the joint is quite satisfactory. Details of the application of the process to killed and rimming steels are given.—L. D. H.

**Fundamental Problems of the Heterogeneous Deformation Induced by Rolling.** L. Hellebrand. (*Sbornik Ostravě*, 1957, **3**, (2), 41–49). [In Czech]. Tafel's law and other proposals for the evaluation of mean elongation of shapes on rolling are critically surveyed and shown to be inadequate, or incompatible with the known requirement of the invariance of volume in plastic deformation. A formula derived by the author is shown to be free from these inconsistencies.

**On the Variation of the Ductility with the Rolling Direction and the Location of the Sample in the Plate.** B. Otta and J. Teindl. (*Sbornik Ostravě*, 1957, **3**, (2), 13–22). [In Czech]. Bend tests on samples cut from various positions of 0·02 and 0·014 in. thick 0·01% C and 4·3% Si transformer sheet showed considerable variations of ductility with sample position in the sheet. The effect is ascribed to differences in the preferential orientation of grains over the area of the sheet. No significant differences in the ductility of O.H. and converter steels of similar composition were detected.—P. E.

**Stationary Convertors for Feeding Rolling Mill Trains.** E. Azaceta. (*Dyna*, 1957, **32**, Dec., 744–758). [In Spanish]. The theory and practice of electricity supply to rolling mill motors is discussed, and it is concluded that feeding from rectifiers is advantageous both in use and for power requirements.—P. S.

**The Manufacture of Two-Patterns for Rolling Mill Housings.** F. Lamm. (*Giesserei*, 1957, **44**, Aug. 29, 520–522). The simultaneous fabrication of two patterns for rolling mill housings, each final casting weighing about 100 tons is described. The pattern design and construction is illustrated in seven diagrams and photographs. A cost comparison, including a numerical analysis as an example, shows the method described to have appreciable advantages over others.—R. J. W.

**Increasing the Load-Bearing Capacity of Plate Mill Housings.** B. A. Morozov, L. T. Timoshuk and B. I. Taratorin. (*Stal'*, 1957, (12), 1107–1110). The weakest part of a plate mill housing is the bridge, especially when it contains holes for the screw-down gear. To improve load bearing capacity, (*a*) the bearing surface of the nut of the adjusting screw is transferred to the lower surface of the bridge or to the zone of compression stresses; (*b*) the radii of the points of transition to the highly stressed zones are increased or, if this is not possible, these transition zones should be shot-peened or roller hardened.

**New Mill Will Roll Tough Steels.** (*Steel*, 1957, **141**, Dec. 2, 99–100). The use of a 32 in. cogging mill at Latrobe Steel Co. is described. It replaces hammer and press forging for superalloys and high-speed steels. One special feature is the use of diamond grooved rolls which distribute the hot deformation more uniformly than flat rolls, particularly in the centre of the ingot.—D. L. C. F.

**The Rolling of Stainless Steel Ingots.** J. Chvojka. (*Hutník*, 1957, **7**, (11), 370–374). [In Czech]. Experiments on the rolling of 18/8 type steels containing about 0·3% Ti and 0·1% Cu lead to the following findings: (*a*) To obtain good surfaces it is necessary to use high pouring rates, to pour in an inert atmosphere, preferably using bottom pouring Rectangular ingots are preferable to octagonal ones. (*b*) One of the main causes of tear formation is the presence of alpha-phase. (*c*) More alpha-phase exists in the interior than near the surface of ingots. (*d*) The amount of alpha-phase may be determined by magnetic methods or by calculation using an empirical formula. (*e*) It would be best to reduce the Cr content to 15–18%, in which case a pure austenitic structure results. (*f*) If the ferrite content exceeds about 10% there is considerable danger of tear formation on heating above about 1200° C; in purely austenitic steels this temperature can be exceeded without danger to the steel. (*g*) The optimum amount and grain size of ferrite results on austenitizing at about 1200° C for 2–4 h. (*h*) The rate of heating above 900° C. can be up to 120° C/h. (*i*) The first passes on rolling should be smoothing passes; it is necessary to turn the billets over several times.—P. F.

**The Development of Optimum Ingot Sizes for Flat Rolled Products.** J. G. Sibakin. (*Reg. Tech. Meet. A.I.S.I.*, 1957, 41–75, discussion 76–79). Calculations are presented for the interrelationships of the units of a hot strip mill. Finishing temperatures, coil length, rolling time, motor loads, entry temperatures and ingot size are related. The sequence of steps for establishing optimum practice is given.

**Carbon Steel: Plates; Structural Sections; Rolled Floor Plates; Steel Sheet Piling.** (*A.I.S.I. Steel Prod. Man.*, 1957, Dec., pp. 65.)

**The Development of Rolls and Profiles for Plates of Endless Tracks of Caterpillar Vehicles.** J. Dobeš and M. Žídek. (*Hutník*, 1957, **7**, (11), 368–370). [In Czech]. The manufacture and design of tractor belt plates from sections is described.—P. F.

**Production of Universal Beams: Modern Rolling Technique.** S. Barlow. (*Iron Coal Trades Rev.*, 1958, **176**, Jan. 24, 217–220). The mill at Lackenby Works of Dorman Loug & Co. is described and the stages in beam rolling are shown.

**A Modern German Plate Mill.** W. Hilterhaus. (*Iron Coal Trades Rev.*, 1958, **176**, Feb. 7, 329–332; from *Klepzig Fachberichte*, 1957, (1)). An account of the 165-in four-high mill of Ruhrstahl A.G., Hattingen and the use of vertical edging rolls.

**Chemical and Structural Heterogeneity of Thick Sheet Rolled from Rimming Steels.** M. Žídek and J. Choleva. (*Hutník*, 1957, **7**, (9), 298–305). [In Czech]. A report is given of a detailed study of ingot heterogeneity occurring in steels with 0·1–0·25% C content. Compliance of the metal in various zones in the ingot with weldability standards was examined. The researches facilitate the most economical way of sectioning the ingots.

**Mechanisation of Rolling Mill Alleys for Thin Hot-Rolled Sheet.** E. Bohuš. (*Hutník*, 1957, **7**, (12), 404–408). [In Czech]. The

introduction of mechanical aids for roll replacement, transport, handling and loading of sheet is discussed.—P. F.

**[Formula for the Planetary Mill].** N. F. Dubrov. (*Stal'*, 1958, (4), 339). A formula for thickness of slab and one for speed of feeding strip into the rolls with a given reduction are given. They were tested on a 10 in. mill rolling strip 3 mm thick from a 1 in. billet at 280 r.p.m.—R. S.

**The Indian Standard for Rolled Steel Beams.** T. V. Joseph. (*Acier-Stahl-Steel*, 1958, April, 183–187). New and improved standards, introduced to coincide with the change over to the metric system, are discussed.—A. G.

**44 Inch Semi-continuous Hot Strip Rolling Mill at Aliquippa, Pa.** (*Engineer*, 1958, **205**, May 30, 829–831).

**Continuous Stainless Steel Strip Rolling Mill Extensions.** (*Engineer*, 1958, **205**, May 23, 777–778; *Engineering*, 1958, **185**, May 16, 632–633). A mill handling slabs up to 8000 lb and rolling strip up to 41·5 in. wide and 380–400 ft long down to 0·1 in. gauge is described. The Steckel principle is used.

**Developments in Stainless Strip Rolling.** (*Anvil*, 1958, **4**, Spring, 4–9). An illustrated description of the Shepcote Lane rolling mills, Sheffield.

**Increasing Production of Wide Stainless Steel Strip.** (*Engineering*, 1958, **185**, May 16, 632–633). An account of the Shepcote Lane Rolling Mills, Sheffield.

**Instrumentation for Iron and Steel.** B. O. Smith. (*Instr. Practice*, 1958, **12**, June, 644–649). A review of furnace controls, strip width and thickness and lamination inspection, pinhole detection, maintenance and future trends is given.

**Decarburization in the Production of Cold-Rolled Transformer Steel.** A. I. Belyakov and A. A. Nefedov. (*Stal'*, 1958, (3), 248).

**[Experiments in Rolling Tubes Produced from Semi-Continuously Cast Ingots].** S. I. Belokurov. (*Stal'*, 1958, (5), 448). A brief note with no details.—R. S.

**Studies on the Rolling of Seamless Steel Tube. II. Measurements and Analyses of Several Loads in Plug Rolling.** Y. Yamada, S. Watake, K. Inoue and H. Nozaki. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 21–28). [In Japanese]. Measurements on an Aetna plug will show that mandrel bar force and roll force decrease gradually as a pierced billet moves through the groove, and roll torque displays a characteristic vibration of the driving system. A linear relationship is shown between (roll force) × (radius of roll) and roll torque and coefficients of friction and pressure between tube and rolls are also examined theoretically.—K. E. J.

**Manufacture of Seamless Tubes by means of the Innocenti-Calmes Process.** J. Gomez Llerenas. (*Second National Congress of the Iron and Steel Industry*, [*Mexico*], 1957, 275–279). The changes of microstructure that occur from ingot stage to finished 6 in. pipe in a 0·16/0·22% carbon steel are recorded. **Processes for the Manufacture of Seamless Steel Tubes.** U. Keller (281–287). A comparison of the various methods is made. **Seamless Steel Tubes in Latin America.** F. Indaco (289–295). Information of the production centres, and production is supplied.

**Mercury-Arc Converters for Large Reversing Drives.** English Electric Co. (*Engineer*, 1958, **205**, June 6, 844–847). A method of control by field reversal is described.

**Operation of a Rolling Mill by Means of Modernized Electric Control.** E. B. Fitzgerald and E. Pell. (*Second National Congress of the Iron and Steel Industry*, [*Mexico*], 1957, 233–246). The advantages of an improved control system on a 38 in. mill are described. **Electrical Equipment for the Continuous Annealing Process for Silicon Steel Strip.** G. J. Hay and H. S. Fegely (111–127). Automatic control systems for each part of the line are described.

**Control Systems for Coilers on Mills and Production Lines.** A. J. Winchester. (*First Nat. Congress Iron and Steel Industry* [*Mexico*], 1955, 331–348).

**The Use of a Computer in a Rolling Mill Office.** R. G. Massey. (*Process Control Autom.*, 1958, **5**, May, 190–195). Work of the operational research dept. of B.I.S.R.A. is reported. The information flow-sheet is given and the processes are diagramatically set out, showing how it is proposed to organize a complete computer system.

## MACHINERY AND SERVICES FOR IRON AND STEEL PLANT

**Mobile Cranes for the Steel Industry.** (*Metallurgia*, 1958, **57**, Jan., 36). A demonstration of the Coles range of mobile cranes designed specifically for applications in the iron and steel industry is reported.—A. G.

**International Works Transport Conference—Liége 1958.** (**Preprints*). **The Main Element of the Cost of Internal Transport Charging.** R. Forterre. (**PE/H*, 56/58, pp. 27). Costs of rail transport services are analysed. **Operating Costs of the Internal Transport Services of Iron and Steel Works.** N. Mévis. (**PE/H*/55/58, pp. 11). Costs of internal transport are examined with regard to economy and costs of and damage to trucks while in the works are included. Factors determining costs are considered and budgetary control is outlined. **A Comparison of the Performance, Lay-Out and Cost of Different Works Railway Systems of German Foundries Supplemented by Mathematical Statistics.** H. Mieth. (**PE/H*/45/58, pp. 17). Installations are examined to obtain a figure for overall cost as they are adapted to the requirement of the individual works and are not competitive and so not directly comparable. An equation is developed and, provisionally, it is established that definite principles of operation can be defined and evaluated. **Steelworks Railway Maintenance, New Methods and Mechanization.** P. Willem. (**PE/H*/58/58, pp. 30). Mechanization of track laying is described and the economics of the process and of other processes of maintenance are evaluated. **Technical and Economic Aspects of Track Maintenance in a Steelworks.** R. Forterre. (**PE/H*/51/58, pp. 13). Team composition and organization are particularly discussed with regard to their duties in track repair. **Modern Methods and Procedures for the Maintenance of Works Railway Track.** A Müller. (**PE/H*/44/58, pp. 34). Comparisons of various procedures are included, also comparisons with Federal Railway standards. **Transport of Lime and Scrap in an Open-Hearth Furnace Steelworks.** W. Gesell. (**PE/H*/57/58, pp. 9). Flow diagrams are presented and installations are discussed. Factors influencing design are examined, but no attempts to find the best solution are made as only exact cost analysis could do this. The paper is aimed at providing a basis for the discussion of technical designs. **Handling of Lime and Scrap in a Steelworks.** A. F. de Lafon and G. Gabrielle. (**PE/H*/53/58, pp. 9). French practice is surveyed. Operations are discussed from point to point for both Bessemer and O.H. installations. **Handling of Lime and Iron Scrap at Cockerill-Ougree.** L. Hubin. (**PE/H*/54/58, pp. 11). Plans are attached.

**The Importance of Modern Internal Transport Systems in the Steel Industry.** L. M. Mayer. (*Second National Congress of the Iron and Steel Industry* [*Mexico*], 1957, 337–340). Brief notes of the problems involved in movement and methods of resolving them, are given.

**Gas Turbines in the Belgian Metallurgical Industry.** A. Jaumotte. (*Chal. et Ind.*, 1957, 388, Nov., 279–287). This paper reviews the types of gas turbines used in the Belgian metallurgical industry and the uses to which they are put.—R. P.

**Continuous and Semi-Continuous Transport at the Cockerill-Ougree Works.** L. Hubin. (**International Transport Conference, Sept. 1957, London*). Ore and coke and waste products are transported. All details of conveyor belts are shown.

**Signal Installations and Communication Techniques used in the Transport of Materials in a Steelworks. I. Review of General Trends in German Steelworks.** K. H. Saul. **II. Signal and Communication Techniques in Steelworks Internal Rail Transport.** H. Bergrath. (**International Transport Conference Sept. 1957, London*).

**Transport by Conveyor Belt in an Iron and Steelworks.** A. C. Brandani. (**International Transport Conference, Sept. 1957, London*). Ore and limestone, coal and coke are carried on 47 belts of a total length of 7590 ft.

**Transport by Conveyor Belts in Iron and Steel Works.** A. Vierling. (**International Transport Conference, London, Sept., 1957*).

**Belt Conveyors in The Iron and Steel Industry.** M. Paris and M. Cordier. (**International Transport Conference, 1957, Sept., London*). The French industry is reviewed excluding iron mining.

**Use of V.H.F. Radio in the Internal Transport of Steelworks.** P. Maury. (**International Transport Conference, Sept., 1957, London*).

## WELDING AND FLAME CUTTING

**Productivity and Thermal Efficiency of Processes of Heating and Welding Metal Sheets with the Flame of the Ordinary Linear Torch.** M. Kh. Shorshovov. (*Source not known). Conditions for heating, fusing and burning through copper and steel sheet at various rates of movement of the torch are investigated and related to the torch characteristics. The findings are related to rapid automatic welding.

**Welding Cast Iron.** (*Fonderia*, 1958, **7**, Mar., 118–120). The characteristics of weldable and non-weldable cast irons are examined and their mechanical and structural properties are studied. Methods of preparation, heat treatment and types of electrodes to be used are discussed.—M. D. J. B.

**Arc Welding with Various Shielding Gases.** A. V. Petrov. (**Svarochnoe Proizvodstvo*, 1957, Aug., 6–10). A is sometimes improved by addition of $H_2$. In presence of Ti, $O_2$, $CO_2$, humidity and $N_2$ may interfere. $O_2$ improves arc stability where oxidation does not occur. Effects on porosity and other properties are noted.

**Welding of Gears Under Protection of Carbon Dioxide.** N. N. Belous. (**Svarochnoye Proizvodstvo*, 1956, (3), 20–22). Low-carbon killed and rimming steels were welded successfully, the $CO_2$ being more effective than a layer of flux.

**Welding Low-Alloy Steel Castings.** N. A. Chapin, C. H. Soldan and L. W. Songer. (*Found. Trade J.*, 1958, **104**, May 22, 597–600). The welding of separately cast parts into a single component is described, especially fabrication of alloy-steel castings for turbines. The welding process and quality control methods are given.

**Ferritic and Austenitic Stainless Steels: Fabrication and Properties.** S. Rowden. (*Iron Coal Trades Rev.*, 1958, **176**, May 9, 1089–1092). Welding characteristics and notes on satisfactory fabrication methods are given and notes on corrosion and heat resistance are added.

**Applications of Unionmelt Welding in the Iron and Steel Industry.** D. E. Knight and G. R. Krois. (*Second National Congress of the Iron and Steel Industry* [*Mexico*], 1957, 129–141). A range of examples is given, many of them pictorial.

**Stainless Electrodes—Type "R".** C. Pfeiffer. (*ESAB Rev.*, 1957, (3), 1–12, 20). [In French]. Compositions of 2 ferritic, 1 austeno-ferritic and 10 austenitic types of stainless steel electrodes with basic or rutile castings are given. Particular attention is given to the OK R303 type with 19% Cr, 9% Ni and 1·5% Mo and micrographs of structures are shown.

**Factors Affecting Weldability of High Strength 1% Chromium–Molybdenum and Other Steels.** F. J. Wilkinson and C. L. M. Cottrell. (*Weld. Met. Fab.*, 1958, **26**, May, 171–184). Various factors giving rise to difficulties in the argon-arc welding of high tensile steel are discussed. The major cause of hot cracking is shown to be sulphur and a relationship between S, P, C and extent of cracking is shown to exist. W is used to fix maximum limits for S and P and its bearing on weldability is considered.

**The Effect of the Shape of the Edges of Strip on the Welded Seam Strength of Tubes.** E. M. Tsygankov. (**Stal'*, 1957, **17**, Aug., 728–730). Strip with various angles of bevel was examined.

**Report on the Strength of Welded Joints in Carbon Steel at Elevated Temperatures.** Petroleum and Chemical Panel of Joint ASTM–ASME Research Committee. (*Trans. A.S.M.E.*, 1958, **80**, Apr., 571–585). Tensile and creep-rupture tests were carried out to determine whether there is any inherent weakness in any portion of a weld at high temperatures in view of the tendency to failure in pressure vessels by cracks adjacent to seams. Tests are still in progress.

**Severe Wear of Pearlitic Steel Weld Metal.** S. Ito, K. Honda and K. Ishiyama. (*J. Mech. Lab.*, 1958, **12**, Mar., 52–59). [In Japanese]. Tests on abrasion without lubricant are reported and a steady state for which an equation is given results. Microstructure and composition are considered, and the movement of wear debris was observed.

**Hydrogen in Mild-Steel Weld Deposits.** N. Christensen, K. Gjermundsen and R. Rose. (*Brit. Weld. J.*, 1958, **5**, June, 272–281). Methods of determination and sources of error are discussed, including CO evolution at 700° C and above in samples with a skin of oxide. $H_2$ is found to increase in single beads from starting point to end crater. Gas bubble formation in beads has been studied by sectioning and the gradients found confirmed by micro-analysis. They are attributed to high-temperature diffusion. Local enrichment near austenite grain boundaries is indicated.

**The Resistance of Welded Constructions, With Particular Reference to Brittle Fracture.** T. M. Noren. (*ESAB Rev.*, 1957, (3), 13–20; *Svetsen*, 1956 (6)). Brittle fracture is reviewed and an account of the NC test given, with results of tests and correlation with other test methods.

**Solder Joints on Plated Rustless Alloys.** S. M. Bien and H. D. Ayers, jun. (*J. Dental Res.*, 1958, **37**, Apr., 368–372). Corrosion tests on Au and 80 Ni–20 Cr plated, 18–8 and 17–7 PH austenitic steels are reported showing the latter to be superior for dental purposes.

**Brazing in Controlled Atmospheres and in Vacuo.** E. V. Beatson. (*Brit. Weld. J.*, 1958, **5**, Apr., 137–143). The importance of moisture and oxygen in reducing atmospheres and their effects in brazing are described and conditions for brazing and their maintenance discussed. The behaviour of oxide films is examined and a possible pattern of behaviour is pointed out. Experimental data on oxide removal, joint penetration and filling in three brazing processes are reported.

**New Process Brazes Aluminium to Stainless Steel.** Stewart-Warner Corp. (*Mod. Met.*, 1958, **14**, Apr. 86). The Alcres process carried out in a furnace at about 1100° F is referred to.

**Combustion of Metals in Oxygen.** A. V. Grosse and J. B. Conway. (*Ind. Eng. Chem.*, 1958, **50**, Apr., 663–672). The development of the Al powder–$O_2$ torch for cutting through refractories is described.

## MACHINING AND MACHINABILITY

**The Machinability of Type A Leaded Steels.** E. J. Paliwoda. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 42, pp. 19. The effects of chemical composition variations are discussed and appear to be similar to those affecting non-leaded O.H. free-cutting steel.—E. E. W.

**Shear-Strain Rate in Metal Cutting and its Effects on Shear-Flow Stress.** D. Kececioglu. (*Trans. A.S.M.E.*, 1958, **80**, Jan., 158–168). A relationship is derived from which the average shear-strain rate in the shear zone may be calculated provided average shear-zone thickness is known. It is found that an increase in the shear-strain rate is accompanied by a significant increase in shear-flow stress.—A. G.

**Temperature Distribution at Tool-Chip and Tool-Work Interface in Metal Cutting.** B. T. Chao and K. J. Trigger. (*Trans. A.S.M.E.*, 1958, **80**, Feb., 311–320). A noniterative method for computing temperatures at tool-chip and tool-work interfaces is presented, together with the three dimensional temperature distribution at the tool top surface.—A. G.

**Shear-Zone Temperature in Metal Cutting and Its Effects on Shear-Flow Stress.** D. Kececioglu. (*Trans. A.S.M.E.*, 1958, **80**, Apr., 541–546). Relationships are given for the calculation of mean temperature in both oblique and orthogonal cutting. Calculations are made for SAE 1015, 118 Bhn seamless tubing for a range of conditions and give values from 410–840° F. The effect on mean shear-flow stress is studied.

**Force Components, Chip Geometry and Specific Cutting Energy in Orthogonal and Oblique Machining of SAE 1015 Steel.** D. Kececioglu. (*Trans. ASME*, 1958, **80**, Jan., 149–157). A three-component, SR–4 strain-gauge, lathe dynamometer is described, using which cutting data have been obtained for SAE 105 steel. Speeds from 125 to 750 ft. p. m. and feeds from 0·004 to 0·012 i.p.v. were investigated.—A. G.

**Experimental Measurement of Metal-Cutting Temperature Distributions.** G. S. Reichenbach. (*Trans. A.S.M.E.*, 1958, **80**, Apr., 525–540). A radiation method using a photocell and a 0·005 in. single embedded wire used as a thermocouple are described. The former gives peak temperature, but not shear-plane temperature distribution. Removing the wire in a chip gives an indication of the temperature field. (24 refs.).

**A Tool-Work Thermocouple Compensating Circuit.** K. J. Trigger, R. K. Campbell and B. T. Chao. (*Trans. A.S.M.E.*, 1958, **80**, Feb., 302–310). A compensating circuit is described which facilitates the use of the tool-work thermocouple for interface temperature measurements. Conditions for complete compensation are explained and evidence for the reliability of the method cited is presented.

**On the Basic Mechanics of the Grinding Process.** W. R. Backer and M. E. Merchant. (*Trans. A.S.M.E.*, 1958, **80**, Jan., 141–148). Experimental evidence shows the dependence of grinding mechanics on the length and area of the undeformed chip and on the cutting speed. Wheel wear varies only with metal removed.—A. G.

**An Experimental Study on Chatter Vibrations in Grinding Operations.** S. Doi. (*Trans. A.S.M.E.*, 1958, **80**, Jan., 133–140). The causes and characteristics of vibrations encountered during the grinding of metals have been investigated. From this aspect a plain bearing is superior to a ball bearing for preventing vibration of the rotating wheel.—A. G.

**Powder-Metal Tool Shanks Improve Quality and Speed of Machining with Carbide Tips.** C. G. Erickson. (*Machine Shop Mag.*, 1958, **19**, June, 339–342).

**Influence of Electric Current on Tool Wear.** V. Solaja and H. L. Hughes. (*Research*, 1958, **11**, May, 207–208). (A letter). Turning was carried out with a current passing from tool to workpiece, either positive or negative. No effect was observed with currents up to ± 10 amp. However, at 45 amp an improvement of surface finish was produced. Care must be taken to avoid sparking with these high currents.

**Hobbing after Hardening Avoids Distortion.** M. E. Samuelson. (*Metalw. Prod.*, 1958, **102**, June 13, 1033–1035). Gear treatment is discussed.

**Electric Spark Machining of Metals.** J. Staňek. (*Czech. Heavy Ind.*, 1958, (5), 33–46). An illustrated account with a review of the Sparcatron and anode-mechanical processes is given. Characteristics of the processes are described and surface quality and precision and cutting speeds are given.

## CLEANING AND PICKLING

**Descaling Iron.** S. Vučkovic and D. Ratkovic. (*Zastita Mat.*, 1955, **3**, Apr., 130–137). A review of the mechanism of formation and of the methods of removal of scale by mechanical methods, pickling and electrolysis.

**Finishing Pointers.** J. B. Mohler. (*Met. Fin.*, 1958, **56**, March, 69). Considerations governing the choice of cleaning cycle are discussed, together with methods available.

**On Shot for Peening. VI. Effect of Shot on the Cleaning Effect.** M. Uchiyama and K. Kamishohara. (*Tetsu-to-Hagane*, 1958, **44**, Feb., 157–162). [In Japanese]. Tests were made on self-hardening Ni–Cr–Mo steel specimens. The peening effect is divided into the residual stress and the cleaning effects. The residual stress effect was reduced by heating above 300° C, and the cleaning effect depended on the initial surface condition. The shape of the shot affected both processes. (15 references).—K. E. J.

**The Kolene Process—a Salt Bath Process for Cleaning the Surface of Workpieces.** K. Falkenmayer. (*Metalloberfläche*, 1957, **11**, Sept., 297–304). A description is given of the scope and mode of operation of two forms of the American Kolene salt bath process, i.e. Kolene 15 and Kolene E (the electrolytic modification). Examples of the use of the former method are in stripping lacquer and de-scaling cold-worked high-alloy parts, the Kolene E process being used for cleaning iron castings and hot-worked high alloy materials.

**Machines and Appliances for the Surface Treatment of Metals.** K. Schrödter. (*Metalloberfläche*, 1957, **11**, Dec., 380–384). A survey is given of the sections of the machine tool exhibition (held in Hanover last year) dealing with machinery and equipment for metal degreasing and cleaning, grinding and polishing, metal spraying and induction heating. A number of illustrations is included.

**Pickling Steel Castings.** (*Found. Trade J.*, 1958, **104**, May 8, 555). Special tanks installed by David Brown Industries at Penistone are very briefly described.

**Pickling, Descaling and Derusting of Steels.** W. Bullough. (*Met. Rev.*, 1957, **2**, (8), 391–406). Disposal and recovery of spent liquors is included. (51 refs.).

**Spray Cleaning, Pickling and Phosphating.** A. J. Steiger. (*Met. Fin.*, 1958, **56**, March, 48–51). Recent Russian studies in the field of high speed automatic jet cleaning processes are summarized.—A. G.

**The Effluent Problem in Pickling Plant and Its Solution.** G. Rättig. (**Blech*, 1955, (3)). Use of the Zahn rotary crystallizer (for $FeSO_4$, $7H_2O$) is described.

## PROTECTIVE COATINGS

**[Protective Coatings].** *Metal Finishing Guidebook and Directory*, 1958, pp. 678). **Plating Room Layout.** J. J. Martin jun. (13, 16, 18, 20, 21). **Acid Resisting Floor Construction.** L. E. Wybel (21, 22, 24–26, 28). **Mechanical Exhaust for Plating Rooms.** F. W. Arndt (28, 30–50, 52). With a table of allowable concentrations of vapours, sections on hood and duct design, a friction chart and brief accounts of fans, belts, motors, stacks, materials of construction and costs. **Essentials of Plating Rack Design.** W. E. Belke (52–55, 58, 61, 62, 64–66). **Anodizing Racks** J. E. Bunch (66–67). **Electrical Power for Plating. 1. Motor Generators.** W. E. Schwarz (67–68, 70–72, 74–75). **II. Rectifiers.** J. E. Mungenast. (76, 78, 80, 82, 84, 86, 88). **III. Plating Tank Wiring.** N. Hall (88–91). **Corrosion Resistant Tanks and Linings.** M. Nadel. (91–92, 94, 96, 98, 100, 102). **Heating Plating Solutions.** G. B. Hogaboom jun. (102, 104). **Cooling of Plating Solutions.** M. Rubinstein. (106, 108, 110, 112–113). **Agitation of Plating Solutions.** M. Rubinstein. (114–116, 118–120). **Control and Treatment of Metal Finishing Wastes.** J. C. Hesler. (120, 122, 124, 126, 128–133). **Polishing and Buffing.** H. L. Kellner. (135–136, 138, 140, 142, 144, 146, 148–159). **Surface Finishing of Stainless Steels.** L. F. Spencer. (161, 162, 164–168, 170). **Buffs for All Purposes.** E. F. Doyle. (170, 172, 174, 176–181). **Abrasive Blasting.** V. F. Stine. (181–189). **Barrel Finishing.** A. S. Kohler. (190, 192, 194–196, 198–204, 206–208, 210, 212–229). **Solvent Vapour Degreasing.** H. Nulle. (231–232, 234–236, 240, 242). **Solvent Recovery and Conservation.** M.

Randall. (242–244). **Metal Cleaning.** S. Spring. (244, 246, 248, 250, 252–254, 256, 258, 260, 262, 264). **Pickling and Acid Dipping.** N. Hall. (264, 266–273). **Salt Bath Descaling.** H. L. Alexander. (274–275). **Preparation of Basic Metals for Plating.** N. Hall. (275–283). **Preparation of Metals for Hard Chrome Plating.** A. Logozzo. (288–291). **Plating Solutions and Operating Data.** N. Hall. **Arsenic.** (299). **Brass.** (299–300). **Bronze.** (300, 302). **Cyanide Cadmium Plating.** R. O. Hull. (302, 304, 306, 308). **Chromium Plating.** G. Dubpernell. (308, 310, 312, 314, 316, 318–319). **Acid Copper Plating.** L. Packman and A. T. Marinaro. (319–321). **Cyanide Copper Plating.** B. D. Ostrow and F. I. Nobel. (322, 324, 326, 328–331). **Fluoborate Copper Plating.** A. E. Carlson and C. Struyk. (331–332, 335). **Iron Plating.** A. M. Max. (353–359). **Lead Plating.** F. C. Mathers. (360, 362–367). **Lead-Tin Alloy Plating.** A. E. Carlson and C. Struyk. (367–370). **Nickel Plating.** W. H. Prine. (370, 372, 374, 376–381). **Bright Nickel Plating.** E. B. Saubestre. (382, 384–391). **Black Nickel Plating.** A. T. Marinaro and Louis Packman. (391–393). **Tin Plating from Acid Baths.** F. C. Mathers. (405–409). **Tin Plating from the Fluoborate Bath.** A. E. Carlson and C. Struyk. (410–411). **Tin Plating from Alkaline Stannate Baths.** F. A. Lowenheim. (411–417). **Tin-Nickel Alloy Plating.** F. A. Lowenheim. (418–420). **Tin-Zinc Alloy Plating.** F. A. Lowenheim. (420–424). **Acid Zinc Plating.** R. O. Hull. (424–425). **Cyanide Zinc Plating.** R. O. Hull. (425–427). **Barrel Plating Fundamentals.** T. R. Gill. (429–430, 432). **Filtration of Plating Solutions.** J. B. Mohler. (445–446, 448, 452–457). **Rinsing Techniques.** J. B. Kushner. (457–463). **Deionization for Electroplaters.** W. S. Morrison. (464, 466–467). **Immersion Plating.** N. Hall. (469–473). **Electropolishing.** C. L. Faust. (473–483). **Stripping Metal Coatings.** N. Hall, G. B. Hogaboom, jun. and J. B. Mohler. (483–484, 486–492). **Phosphate Coatings.** S. Spring. (536–545). With analytical control methods. **Testing Porosity, Adhesion and Hardness.** W. H. Prine. (547–550). **Thickness Testing of Electrodeposits.** E. A. Hodges. (551–552, 554–561). **Salt Spray Testing.** G. B. Hogaboom, jun. (561–565). **Control of Plating Baths with Plating Cells.** R. O. Hull. (566–569). **pH Control.** E. A. Hodges. (569–573). **Chemical Analysis of Plating Solutions.** N. Hall. (573–589). **Identification of Deposits.** N. Hall. (589–590). **Tables and Data Sheets.** (591–613).

**Anti-Rust Coatings and Their Choice in Practice.** P. Orlowski. (*Mét. Constr. Mécan.*, 1956, **88**, Dec., 1027–1033). A review is given of commercial methods of corrosion prevention and of the theory of corrosion.

**Flexibility and Labour Reduction Feature New Plating Department.** D. A. Sigman. (*Met. Fin.*, 1958, **56**, March, 65–68). A semi-automatic plating department is described, which cost only 25% more and requires one-sixth the labour of hand operation. Details of the plating cycle are given.

**Measuring Loads of Solid Flat Steel Parts.** G. C. Field. (*Met. Fin.*, 1958, **56**, March, 70–71). A nomograph is given and its use described for estimating loads for such processes as plating, tumbling and acid dipping.

**Neutralizing Waste Water from Electroplating Plant.** D. Aleksander. (*Zaštita Mat.*, 1955, **3**, May, 166–168). Cyanide disposal is dealt with particularly.

**Automatic Plating Installations and the Tasks of the Electro-plating Supervisor.** D. Ausen. (*Draht*, 1957, **8**, Aug., 339–340). Some of the points are dealt with which demand the attention of technical supervisors of automatic electro-plating installations.

**New Chemical Process Plates Resistant Nickel.** R. B. Norden. (*Chem. Eng.*, 1958, **65**, Jan. 13, 172, 174). An account of the Niphos process using nickel oxide and diammonium phosphate spray which is then heated in $H_2$ at 1650° F.

**New Plating Process for Corrosion and Wear Resistance.** (*Ind. Fin.*, 1957, **9**, Nov., 921–926). The Kanigen process for the chemical plating of nickel-phosphorus alloy layers is described. Applications of the process to improve wear and corrosion resistance, for building up of worn parts and as intermediate coatings are discussed.

**Coating Steel with Fluid Zinc.** S. Socha. (*Prace Inst. Ministerstwa Hutnictwa*, 1957, **9**, (6), 269–279). Effects of metallic additions to the Zn on the solubility of iron in the zinc bath are examined and Pb and Cd are found to increase solubility. The work was carried out on various commercial grades of zinc to which most of the findings refer.

**Electrically Heated Baths for Dip Metallising.** K. Janecký. (*Hutník*, 1957, **7**, (12), 408–412). [In Czech]. The advantages of electrical heating for baths used for tinning and hot galvanizing of wires, strip and tubes, and for annealing of wires in liquid lead are discussed. It is suggested that, even though in Czechoslovakia, at present, electrical heating is more expensive than heating by gas, this particular economic disadvantage would, on the whole, be outweighed by the greater facility in controlling electric furnaces, and by other desirable features. In an editorial comment it is suggested that electrical heating is more advantageous than the use of gas only in the case of smaller baths. Also control of a gas heated modern bath is quite effective.—P. F.

**Carbon Steel Sheets.** (*A.I.S.I. Steel Prod. Man.*, 1957, Nov., pp. 68). Metallurgy, manufacture, quality descriptions, compositions, thickness and weight data and tolerances are given. Also data for porcelain enamelling, galvanizing and terne sheets and for formed roofing and siding sheets are tabulated.

**Heat Control for Galvanising.** (*Esso Oilways*, 1957, **9**, (2), 6–8). A new burner system is described.

**Galvanising and Coating with Other Metals as a Protection against Corrosion.** A. Piener. (*Zastita Mat.*, 1955, **3**, Feb., 49–54). A review of known basic methods is given in a simple form. Problems of porosity and choice of metals for coating are mentioned.—M. de O. T.

**Purification of Effluents from Galvanizing Plants.** S. Sivanovic. (*Zastita Mat.*, 1955, **3**, Mar., 87–92). The author explains the necessity for, and importance of, such purification, and outlines the normal methods of removing cyanides, chromates, acids and harmful metallic impurities. He describes a practical plant for separating out these metals by means of their electrolytic potentials.

**Paint Finishing of Hot-Galvanised Steel.** J. F. H. Van Eijnsbergen. (*Peint. Pig. Ver.*, 1958, **34**, Jan., 5–9). Mechanical or chemical pre-treatments and the types of paint or other coatings used are described. High-zinc paints are considered particularly. (15 references).

**Progress of Bright Tin Plating.** (*Tin*, 1957, Winter, 1–3). Flow brightening and electrodeposition are briefly described.

**Some Advances in Tin Plate Technology.** W. E. Hoare. (*Met. Prog.*, 1958, **73**, Jan., 91–96). An illustrated review of modern developments in tin plate is presented. Closer tolerances, annealing for both ductility and stiffness, electrolytic and roller coating machinery, electronic control of high speed lines and new devices for measuring corrosion resistance are considered.—B. G. B.

**Hot-Tinning.** A. Herz. (*Galvano*, 1957, **26**, June, 47–48). A brief review of degreasing, pickling and flux.

**Manufacture of Tinplates in India.** Y. A. Gopal Rao. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 223–229). The manufacture of tinplate at the works of the Tinplate Co. of India (Private) Ltd. at Golmuri, Jamshedpur, is briefly described and recent developments in the industry are mentioned.—B. C. W.

**The Direct Chloride Process for Tinning Cast Iron.** C. J. Thwaites and J. J. Day. (*Metallurgia*, 1957, **56**, Dec., 263–270). The process is shown to give adequate adhesion to white metal bearing alloys and provided that the preliminary mechanical preparation of the surface is adequate before treatment, variations in composition of the iron and conditions of tinning or white metalling had little effect. The formation of a continuous layer of $FeSn_2$ is necessary to give high bond strength to the coatings.—A. D. H.

**Mottling on Tin Plate.** H. Eggers. (**Arch. Eisenhütt.* 1957, **28**, Dec., 777–783). The phenomenon of mottling in detinned plate occurs in hot-tinned sheet only. The formation and extent of mottling are determined by the smoothness and metallic cleanness of the sheet: sheet thickness must be less than 0·5 mm, and the fluxing agent must have vigorous boiling mobility. Mottling is almost certainly equivalent to the binary compound $FeSn_2$ which always occurs in tinned sheeting.—L. J. L.

**Surface Perfection of Tinplate.** W. Richards. (*Tin-Printer & Box Maker*, 1958, **34**, Jan. 6). Grease lines and porosity effects are described.

**How to Get Stronger Al-Fe Bonds.** S. Storchheim. (*Iron Age*, 1957, **180**, Dec. 5, 136–138). The results of tests illustrating the effect of pressure on Al-Fe hot bonding operations are described. The effects of temperature and pressure in increasing the thickness of the alloy boundary layer was noted, and the strength of the bond was found to deteriorate as this layer grew.

**Cadmium Plating: How to Avoid Embrittlement.** (*Steel*, 1957, **141**, Nov. 11, 132–134). Three techniques developed at Lockheed Aircraft Corp. for applying Cd coatings without causing $H_2$ embrittlement, are described. They are (1) maintenance of high current density in the cyanide bath; (2) a cyanide bath with nitrate additions to suppress $H_2$ formation; (3) vacuum metallizing.

**Lead Coated Strip and its Defects.** J. Teindl and L. Bezecný. (*Hutník*, 1957, **7**, (8), 273–275). [In Czech]. The production of lead-coated strip used for electrical underground junction boxes and other electrotechnical purposes is discussed, and common defects and their origins are considered.—P. F.

**Metal Spraying—Development and Application.** S. J. Oechsle jun. (*Met. Fin.*, 1957, **55**, 67–71, 76). Examples of application of metal spraying for reclamation of worn parts, prevention of corrosion, and high temperature coatings are discussed.—A. D. H.

**Phosphating Processes and their Applications in Metal Finishing.** D. J. Fishlock. (*Product Finishing*, 1957, **10**, June, 65–76). **1—General Principles.** A brief history of the process from 1869 is followed by sections on basic theory and applications. **2—Choice of Plant.** (July, 73–85). Cleaning and pre-treatment, choice of plant for chemical, electrolytic and spray processes and drying plant are considered. **3—Theoretical Aspects.** (Aug., 82–91). The reactions involved and the potentiometric titration curves and their significance are reviewed. The effects of pre-treatment are described and related to coating weight and corrosion resistance, and typical processes are outlined, bath compositions given and the resulting structures shown. The use of accelerators is surveyed and details of the Alochrom process are added. **4—Typical Processes.** (Sept., 94–104, 132). Paint bonding treatments, especially for Al and its alloys, and corrosion-resisting treatments, in which a sealer is applied, for springs, screw threads and for large structures, on which spray treatments are used are surveyed. Engineering applications are then considered for friction and lubrication purposes and for cold-forming. **5—Process Control.** (Oct., 84–93). Sampling and chemical control, performance and normal and accelerated weathering tests including salt-spray, humidity and weatherometer methods are reviewed.

**Ferric Phosphate Precipitation in Phosphating Baths.** S. L. Eisler and P. G. Chamberlain. (*Ind. Fin.*, 1957, **9**, Nov., 939–942). The solubility of ferric phosphate in twelve zinc phosphating solutions was determined by using a radio-isotope technique. The optimum conditions were obtained by maintaining the bath at 140° F. and heating to 205° F. after the charge had been introduced. The nitrate accelerator concentration should be 1–2·5%.—A. D. H.

**New Look at Plating Room Power.** C. F. Ivins jun. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1957, 79–86; discussion 163). A review of D.C. power equipment, old and new, including rectifiers.

**The Sparcard Hard-surfacing Process.** (*Machinery*, 1958, **92**, Mar. 21, 687–688; *Metalw. Prod.*, 1958, **102**, Mar. 28, 554–555). A modification of the Sparcatron spark-machining unit has been developed for the deposition of hard metals on steel surfaces.

**High Temperature Coatings.** F. Hofstatter. (*Ind. Fin.*, 1958, **10**, Feb., 34–36). Materials for coating aircraft and missiles. (Al, Cr, Ni, Cu, Mo, stainless steel and silicones).

**New Japanese Hard Chromium Plant.** Y. Hirasawa. (*Met. Fin.*, 1958, **56**, Feb., 55–57). An illustrated account of the installation at the Aikoku Plating Industry Works, Tokyo.

**Study on the Improvement of Chromium Plating.** J. Socha and T. Zak. (*Prace Inst. Mech.*, 1957, **6**, (19), 62–70). [In Polish]. A survey of Cr plating methods is given. The effects of $K^+$, $SiF_6^{++}$, $Sr^{++}$ and $SO_4^{--}$ ions added to the solution of $CrO_3$ have been investigated. The cathodic efficiency of Cr deposition and the extent of bright coating have increased, while the microhardness has decreased slightly.

**Bright and Semi-Bright Crack-Free Chromium.** E. J. Seyb, A. A. Johnson and A. C. Tulumello. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1957, 29–35; discussion 158–159). The process and the deposits formed are described and salt and acid spray and outside exposure tests are discussed.

**Finishing Facilities for a Modern Railroad.** G. H. Poll jun. (*Products Fin.*, 1958, **22**, Mar., 24–35). An illustrated account of the Cr and Ag plating, case hardening, grit-blasting and painting departments at Roanoke, Va.

**Influence of the Acidity of Solutions on Cathodic Polarisation during Deposition of Cobalt and Nickel.** Z. A. Solov'eva and O. A. Abrarov. (*Zhur. Fiz. Khim.*, 1956, **30**, (7), 1572–1578). [In Russian]. Experiments with an oscillograph are described showing the relation between polarization and the pH of various aqueous solutions of metals of the iron group. They are based on deposition at the electrode and show that on slightly raising the pH of a solution, polarization falls, whilst on increasing the temperature this condition tends towards higher acidity values. A suggestion is offered as to the chemical origin of the cathodic polarization and it is assumed that changes in polarization may be due to a rearrangement of the metal structure.

**The Influence of the Physical Metallurgy and Mechanical Processing of the Basis Metal on Electroplating. IV. The Effects of Different Ferrous Metals on the Performance of a Watts Nickel Deposit.** M. H. Jones, Chih-Yen Lu and J. Zajdowski. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1957, 53–69; discussion 162). Differences between 0·0005 and 0·001 in. deposits are demonstrated the former due to large inclusions. There is shown to be a basic corrosion rate independent of the basis metal.

**Further Studies on Nickel-Iron Alloy Electrodeposits.** I. W. Wolf. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1957, 121–123; discussion 166–167). Properties are related to corrosion resistance and possible use as information storage units is noted.

**The Latest Developments in Electroplating with Ultrasonics.** S. R. Rich. (*Proc. Ann. Conv. Amer. Electroplaters' Soc.*, 1957, 87–90; discussion, 163–164). A review of applications to the plating of Ni, Zn, Cr, and Ag.

**Fabricating Continuous Galvanized Steel.** E. W. Horvick. (*Steel Proc.*, 1958, **44**, Jan., 43–46. The processes of galvanizing are reviewed and choice of steel (rimmed, semi-killed, killed and capped) is considered.

**On the Solubility of Iron in Fused Tin.** I. A. Kakovskii and N. S. Smirnov. (*Izvest. Akad. Nauk Otdel. Tekn.*, 1957, (11), 44–51). The solubility of iron in fused tin, has been studied within the range of temperature of formation of $FeSn_2$, i.e. between 250° and 480° C, which is the temperature of the tinning process.

Formulæ have been obtained for calculating the solubility of iron under these conditions, and explanations are offered on the behaviour of some metalloids forming compounds with iron.—L. H.

**Post-War Developments of the Tinplate Industry in Western Europe. 2. France and the Saar Territory.** W. E. Hoare and P. Déhais. (*Sheet Metal Ind.*, 1958, **35**, Jan., 47–54). The Carnaud plant, Hayange plant, SOLLAC Installations, Forges et Aciéries de Dilling, Sidelor and Forges d'Hennebont are briefly described. **3. Belgium and the Netherlands.** W. E. Hoare. (Mar., 181–187). Accounts are given of the Phenix Works and the Ferblatil division of Cockerill-Ougrée, both near Liége, and the Breedband plant at Ijmuiden, Holland.

**The Application of Precoated Steel Sheets In Industry. 2.** E. Marks. (*Sheet Metal Ind.*, 1958, **35**, Mar,. 195–201). Tinned and terne sheets are discussed and then phosphate-coated and blue planished sheets, aluminizing and plastic coating. Uses are discussed.

**Amino-Acid Cadmium Plating Solutions for Ultra High Strength Steel.** P. H. Vlannes, S. W. Strauss and B. F. Brown. (*Electrop. Met. Fin.*, 1958, **11**, Mar., 85–87; *NRL Report* 4906, *P.B.* 121836). Hull cell tests and other properties of Cd plating from baths containing glycine, β-alanine and α-amino-*n*-and-*iso*-butyric and -caproic acids are reported.

**Phosphating: A Pretreatment for the Cold-Forming of Steel.** W. Machu. (*Stahl u. Eisen*, 1958, **78**, Mar. 20, 383–387). A review of recent publications and patents on phosphating, (45 references).—T. G.

**The Protection of Metals.** O. L. Torre. (*Ing. e. Indust.*, 1957, **25**, Oct., 111–114). [In Spanish]. A brief account of the theory and practice of phosphating is given. Characteristics of the coatings and typical applications are explained.—F. S.

**How Grit Blasting Improves Phosphate Coatings.** J. Knanishu. (*Met. Fin.* 1958, **56**, March, 57–62). Test work is described indicating that preliminary grit blasting increases the rate of formation of the coating formed in a phosphating solution. An explanation of this is advanced.—A. G.

**The Protection of Metals by Complexes of Polyvinyl Butyral, Phosphoric Acid and Chromium Derivatives.** P. Duval. (*Corros. et Anticorros.*, 1957, **5**, June, 189–193). A description is given of wash primers, their constitution, action and method of application.

**New Developments in Wire Enamelling Machines.** F. Rüb. (*Wire*, 1958, Apr., 32–33). Machinery developed for continuous, in-line enamelling of heavy gauge wire and wire strip is described in brief.—J. G. W.

**Glassed Steel for the Chemical Industry.** D. K. Priest. (*Ind. Eng. Chem.*, 1958, **50**, May, 75A–76A). An account of clear enamelled steel and its uses for chemical plant is given.

**Influence on the Life of Paint of Pre-Treatment and the Degree of Oxidation of the Surface Before Painting.** K. Trägardh. (*Corros. et Anticorros.*, 1957, **5**, June, 169–173). Long-term trials in Sweden showed that the life of a coat of paint applied to steel was influenced considerably by the degree of rusting of the metal surface and its preliminary treatment. The life of the coating was greatly increased if pre-treatment and painting were carried out before the steel surface had commenced to rust.—L. D. H.

**Prepainted Steel Strip.** Coated Strip Ltd. (*Sheet Met. Ind.*, 1958, **35**, May, 395–399, 412A). An illustrated description of plant and works practice is given.

## POWDER METALLURGY

**Powder Metallurgy: Its General Development and Its Future Possibilities for Mechanically Refractory Parts and Cermets.** R. Kieffer and R. Meyer. (*Chim. Ind.*, 1958, **79**, May, 589–599). Carbide and oxide cermets are reviewed. (69 refs.).

**Iron Powder, Basic Information.** (*Höganäs Iron Powder Handbook*, Vol. 1, 1957; loose-leaf, some sections still to be issued). **History of Iron Powder.** N. H. Brundin, (pp. 2). A brief outline. **Commercial Iron Powders.** S. I. Hulthen. (*Section A, Chap.* 10, pp. 8). Methods of production are surveyed in general terms and micrographs of the products are shown. **Properties of Iron Powders.** S. I. Hulthen. (*Section A. Chap.* 20, pp. 4). Analyses, particle sizes and the strength of test bars sintered in $H_2$ are given. **Commercial Importance and Technical Use of Iron Powders.** S. I. Hulthen. (*Section A* Chap. 30, pp. 4). Statistics are given and uses for welding, powder metallurgy and flame cutting are outlined. **Treatment of Iron Powders: Thermal.** S. I. Hulthen. (*Section C.* Chap. 10, pp. 1). Reducing and annealing processes are indicated. **Lubrication.** S. I. Hulthen and N. H. Brundin. (*Section C. Chap.* 20, pp. 6). Lubricants used and their effects on ejection force are summarized. **Alloying Additives.** S. I. Hulthen. (*Section C, Chap.* 30, pp. 4). Graphite, Cu, P, S and Ni are briefly reviewed. **Pressing and Tooling. Powder Compacting Methods.** S. I. Hulthen. (*Section D. Chap.* 10, pp. 10). Behaviour under pressure, green properties and compacting methods are outlined. **Various Tooling Principles.** S. I. Hulthen. (*Section D, Chap.* 20, pp. 35). Presses and their actions are illustrated diagrammatically and described in outline. **Sintering. Thermal Treatment Prior to Sintering.** S. I. Hulthen. (*Section E, Chap.* 10, pp. 1). **Basic Aspects of Sintering.** G. Bockstiegel. (*Section E. Chap.* 20, pp. 16). Effects of temperature and time and the strength of sintered materials, metal structure, recrystallization and grain growth, plastic flow and sintering mechanisms are outlined. **Sintering Atmospheres.** O. Wiberg. (*Section E. Chap.* 40, pp. 17). Oxidizing, reducing, carburizing, inert and nitriding conditions are considered. The production of these atmospheres is reviewed, also measurement and control. **Designing Metal Powder Parts, General Aspects.** S. I. Hulthen. (*Section F, Chap.* 10. pp. 15). Processes, tolerances and design recommendations are given. **Subsequent Treatment of Sintered Iron and Steel Parts: Joining.** S. I. Hulthen and H. G. Taylor. (*Section G Chap.* 10, pp. 2). **Peen Plating.** G. H. Jenner. (*Section G, Chap.* 60, pp. 7). The process is outlined and compared with electroplating. It consists of cold welding in a tumbling barrel. **Layout of a Pilot Plant.** S. I. Hulthen and H. G. Taylor. (*Section H, Chap.* 10, pp. 3). **Layout of an Extensible Production Plant.** S. I. Hulthen and H. G. Taylor. (*Section H, Chap.* 20, pp. 5). A flow sheet with some account of the components is given.

## FERRITES, CERMETS, AND CARBIDES

**Sintered Ceramic Chiselling Materials.** M. J. C. Matthijsen. (*Metallbewerking*, 1958, (22), 452–457; (23), 467–470). An account of the composition, properties and manufacture of sintered hard products for metal-working tools is given.

**Iron–Copper–Graphite Sintered Materials.** P. U. Gummeson and L. Forss. (*Planseeber.*, 1957, **5**, Dec., 94–101). The properties of sintered iron and graphite, with varying amounts of copper up to 8% were examined. With 5% Cu and less, the material has the advantages of strength and resistance to the influence of the sintering atmosphere. The addition of small amounts of copper and of graphite are beneficial, but the sintering atmosphere must be controlled.—L. D. H.

**Cation Substitutions in $BaFe_{12}O_{19}$.** A. H. Mones and E. Banks. (*J. Phys. Chem. Solids*, 1958, **4**, (3), 217–222).

**Ferromagnetic Resonance in Polycrystalline Ferrites.** J. Snieder. (*Appl. Sci. Res.*, 1958, **7B**, (3), 185–232).

## PROPERTIES AND TESTS

**Research in 1957.** (*Metro.-Vic. Gaz.*, 1958, **29**, Mar., 76–93). Work on stress analysis and metal cutting (82–83), corrosion behaviour of steel and other metals in $CO_2$ at high pressure (83), carbides and ceramic tools (84), annealing and ageing of sheet steel (85) and testing by simulation of annealing on strip (85–86) is briefly referred to.

**Surface-Testing Instruments for Workshop and Laboratory.** A. Metz. (*Maschinenwelt Elek.*, 1958, **13**, Feb., 50–53). The principle and mode of operation of various modern instruments for measuring surface quality are described, with illustrations of the equipment.—L. D. K.

**Importance of Inspection of Material in the Steel Industry.** M. Garza Lopez. (*Second National Congress of the Iron and Steel Industry [Mexico]*, 1957, 347–350). The necessity of inspection is discussed, its advantages listed, and test methods described.

**A Survey of the Structural Properties of Some High Strength Sheet Steels.** M. A. Meleon. (*North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Report* 101, 1957, Apr., pp. 25). Stainless steels 420, 422, 422M, AM350 and 17–7 PH are reported on and the properties of Al and Ti are compared with those of steel. Tri-cent low-alloy and Thermold J tool steel are also considered. Heat treatment is outlined and tension and compression values at ordinary and elevated temperatures, fatigue, creep and corrosion-resistance are also mentioned and tear strength for some of the materials are given. Fabrication is reviewed.

**Evaluating the Quality of Boiler Plate.** V. I. Dorokhov, A. V. Lopatin and V. A. Molotkov. (*Stal'*, 1958, (4), 348–352). The method of evaluation based on fracture tests is too dependent upon external conditions and is replaced by macro examination and sulphur prints. The structure must be considered in relation to plate thickness.

**A New Counter Goniometer for Determining the Texture of Sheet Materials.** H. Neff. (*Z. Metallkunde*, 1956, **47**, Sept., 646–649). Pole figures are recorded on a spiral using Cr–$K_\alpha$ radiation. Each record takes 6 min.–3 h according to the accuracy required.

**Correlation of Torsional and Tensile Prestrain Effects on Fracture Properties.** I. Rozalsky (*Proc. A.S.T.M.*, 1956, **56**, 621–644). Spheroidized SAE 1020 steel (and annealed Cu) were examined between 75° and −321° F to determine the effects of room temperature tensile and torsional prestrain on tensile fracture properties. Above transition temperature helical "wolf-ear" fracture was obtained after critical or greater than critical amounts of prestrain. At lower temperatures this type of fracture became less pronounced.

**Contribution to the Bending of Special Cast Iron.** F. Bollenrath and A. Erenz. (*Giesserei, Tech. Wiss.*, 1957, (17), July, 919–923). The position on strength investigations on cast iron is first reviewed (20 references). More recent investigations are then described. The determination of the bending stress from deformation measurements is described for cast iron with spheroidal graphite and with acicular graphite structure. The relationship between tensile, compressive and bending stresses is discussed. In an appendix the connection between homogeneous and inhomogeneous stress distributions is calculated mathematically.—E. J. W.

**Strength Under Alternating Torsion Stress of Some Heat-Treatable Steels After Inductive Edge-Hardening.** F. Bollenrath. (*Arch. Eisenhüttenwesen*, 1957, **28**, Dec., 801–806). Torsion stress strength was determined by Vickers hardness measurements in the following steels: 42 MnV 7 (0·43% C; 1·6% Mn; and 0·1% V); 30 CrMoV 9 (0·26% C; 2·4% Cr; 0·15% Mo and 0·2% V); aircraft steel 1620 (0·3 or 0·35% C; 2·3 or 2·6% Cr; 0·1 or 0·2% Mo; 0·35% Ni and 0·23% V).—L. J. L.

**Impact Fatigue Resistance of Structural Steels.** B. N. Das and G. D. Sani. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 103–118). The results of transverse impact fatigue tests on rotating unotched specimens of 5 structural steels are presented and compared with the results of conventional fatigue tests. A description is given of a comparative electrical-resistance strain-gauge method developed to determine the maximum fibre-stress in the impact specimens, and it is shown that when the maximum fibre stress determined in this manner is plotted against the number of impacts a characteristic S-N curve is obtained. The results show that the impact endurance limit is about 85% of the conventional endurance limit, that the relative rating of the steels is the same in each type of test and that there is no relationship between impact fatigue limit and single blow impact strength.—B. C. W.

**Impact Properties of Quenched-and-Tempered Alloy Steels.** J. P. Sheehan and H. Schwartzbart. (*Proc. A.S.T.M.*, 1956, **56**, 483–518, discussion 518–520). Brittle fracture is investigated using 37 steels of which analyses and heat-treatment and grain size are given. Transition temperature is related to tempering temperature and C content for the 1300, 2300, 3100, 4100, 4300, 4600, 5100 and 8600 series steels, and to hardness. The effects of P on steels with and without Mo are shown and also the relation of transition temperature to grain size. Typical fractures are illustrated. A-brittleness (500° F embrittlement) was observed in all samples. B-brittleness appeared in the 2300 series steels and temper brittleness in 0·8% C heats of most of the grades examined.

**Study of Metal-Working Processes. Non-Homogeneous Deformation of Material.** H. P. Tardif. (*Iron Coal Trades Rev.*, 1958, **176**, Feb. 14, 393–395). A survey of methods of study is referred to. Work on metal plasticity is assessed.

**Structural Changes Occurring in Steel on Cold Working.** F. Hrazdil. (*Hutník*, 1957, **7**, (9), 294—298). [In Czech]. Changes in hardness, strength and ductility occurring in direct and inverse impact cold extrusion of solid and hollow steel bodies pre-annealed at various temperatures up to 600° C were studied.—F. F.

**On the Phenomenon of Crack Formation and Propagation.** W. Olszak. (*Bull. Acad. Polonaise Sci.*, 1957, **5**, (6), 377–387). [In English]. Mathematical.

**1956 References on Fatigue.** H. J. Grover and Survey Sub-Committee III of Committee E-9. (*Amer. Soc. Test. Mat.*, 1958, pp. 64). Abstracts are given, 8 per page.

**Observation Concerning Metal Fatigue.** (*N.B.S. Tech. Bull.*, 1958, **42**, Jan., 8). When metal with fatigue cracks is stressed under transparent tape, bubbles are formed under the tape with mild steel and, to a small extent, with stainless. This may be useful to detect the onset of fatigue cracking.

**Fatigue of Metals.—1.** C. E. Phillips. (*Tek. Ukr.*, 1958, **105**, Jan. 2, 11–17). Visual evidence of fatigue failures is mentioned; several types of testing machines and the S/N curve are described. The author also deals with the lack of correlation between fatigue strength and other mechanical properties, effects of mean stress, surface effects and effects of stress distribution on fatigue strength.

**The Effect of Changing Cyclic Modulus on Bending Fatigue Strength.** A. A. Blatherwick and B. J. Lazan. (*Proc. A.S.T.M.*, 1956, **56**, 1012–1033, discussion, 1034–1037). Three series of tests were carried out on solid and hollow 1020 steel specimens. In the first, strain amplitude in the outer fibres was held constant, in the second, constant-stress amplitude tests were made and in the third series moment amplitude was held constant. Constant moment tests gave intermediate values between constant strain tests, giving the longest and constant stress tests, giving the shortest lives.

**The Effect of Size, Shape and Grain Size on the Fatigue Strength of Medium Carbon Steel.** C. Massonnet. (*Proc. A.S.T.M.*, 1956, **56**, 954–978). The importance of electrolytic polishing is shown and a size effect in rotation bending is demonstrated, though not in tension-compression, and in alternate flexure the size effect is small. Curves useful for machine part design are given and the effect of grain size is strikingly shown. Stress gradient is shown to affect fatigue resistance.

**The Propagation of Fatigue Cracks in Sheet Specimens.** N. E. Frost and D. S. Dugdale. (*J. Mech. Phys. Solids*, 1958, **6**, (2), 92–110). Tests on mild steel and other specimens with a central slit were made, measuring the growth of cracks initiated by the slit. In some specimens, a plastic zone was visible and this was related to crack length. The effect of low stresses is erratic but while growth was steady the rate of growth was proportional to length of crack up to 1/8 of specimen width.

**Installation for Fatigue-Testing Gear Wheels.** V. I. Rudnitskii. (*Zavods. Lab.*, 1957, **23**, (11), 1383–1384). [In Russian]. A machine is described in which gear-wheel teeth can be fatigue-tested by bending. It enables the influence of various factors on the fatigue strength of teeth to be studied with any positive asymmetry coefficient of the loading cycle. The scale factor can also be studied for gear wheels and eight wheels can be tested simultaneously. An inertia-type loading device is used, with load recording. Experience and analysis of possible errors suggests that the mean square error for fatigue-limit determination is $\leq 2{\cdot}5\%$.—S. K.

**A Unique Machine for Large Scale Fatigue Testing.** H. V. Cordiano. (*Amer. Soc. Test. Mat. preprint*, 1957, 86 C, pp. 15). A machine on the principle of the dynamic vibration absorber is described with two sets of rotating eccentric discs on parallel shafts 180° out of phase and the absorber is the weighted test specimen. Bending moment is uniform over a 40-in. span, and the machine is designed for a capacity of 400,000 in-lb adjustable from zero in 50 steps. Results on rivetted and welded joints are shown and agree with previous observations.

**Fatigue in Automobile Parts.** Z. Garcia Martin. (*Cien. Tecn. Solda.*, 1957, **7**, Nov.–Dec.). [In Spanish.]. The characteristics of fatigue failure and the influence of metallurgical and mechanical factors on its development are described. The liability of various automobile parts (e.g., crankshafts, key-ways, bolts, springs, etc.) is then discussed.—F. S.

**A Review of Methods Employed in the Statistical Analysis of Fatigue Data.** R. Roeloffs and F. Garofals. (*Proc. A.S.T.M.*, 1956, **56**, 1081–1090). **A Study of Statistical Treatments of Fatigue Data.** M. N. Torrey and G. R. Gohn. (1091–1117, discussion 1117–1123). The actual examples are non-ferrous.

**The Effect of Cold Work on the Fatigue Characteristics of an Austenitic Alloy Steel.** B. Cina. (*J.I.S.I.*, 1958, **190**, Oct., 144–157). [This Issue].

**How Grinding Affects Fatigue Strength.** L. P. Tarasov. (*Metalw. Prod.*, 1958, **102**, Feb. 21, 323–327). Good practice did not reduce fatigue strength though severe grinding did. Under some conditions in presence of oil the surface was actually strengthened with rise of fatigue limit. High residual stresses had much less effect than was predicted on the assumption that residual stress had the same effect as applied external stress. Cold work had some effect and compressive stresses may have had. Case hardened steels were not examined and may behave differently.

**The Effect of Alloying Elements on Creep Behaviour.** J. Glen. (*J.I.S.I.*, 1958, **190**, Oct., 114–135). [This Issue].

**Recent Developments in Creep Testing by Cantilever Bending Method.** G. T. Harris, H. C. Child, A. B. Collier, and C. F. West. (*J.I.S.I.*, 1958, **190**, Oct., 136–143). [This Issue].

**Tests on Large Stainless Steel Bellows.** (*Engineer*, 1958, **205**, Jan. 31, 181–182). Tests on welds have been made for steel bellows intended for expansion joints in nuclear reactor gas circuits. Test conditions are described and a fracture is shown.

**How Good Are Leaded Steels in Fatigue?** G. W. Brock and G. M. Sinclair. (*Iron Age*, 1958, **181**, Jan. 9, 59–62). A comprehensive series of tests are reported which compare the tensile and fatigue properties of leaded and non-leaded steels. Tensile and ductility values for leaded steels may be reduced slightly at all strength levels, but the reduction is so slight as to be of little practical significance. The fatigue strengths of leaded steels are below that of non-leaded steels when the ultimate strength is above about 135,000 p.s.i.

The gap between the 2 types of steel widens to 20% with increasing strength. Notched bar strength is less affected.—D. L. C. P.

**Dislocations in Stainless Steel.** W. Bollmann. (*Proc. Stockholm Conf. on Electron Microscopy*, 1956, Sept., 316–318). Studies on creep in 18–8 steel were made. Electrolytic and ionic bombardment methods were used to reveal structure and effects after rolling are shown.

**Destruction of a Large Refining Unit by Gaseous Detonation.** R. B. Jacobs, W. L. Bulkley, J. C. Rhodes, and T. L. Speer. (*Chem. Eng. Prog.*, 1957, **53**, Dec., 565–573). Fracture patterns of a large hydroformer shell are shown. **Effects of Gaseous Detonations upon Vessels and Piping.** P. N. Randall, J. Bland, W. M. Dudley and R. B. Jacobs. (574–580).

**Calibrating Hardness Test Blocks.** (*Mech. World*, 1958, **138**, Jan., 30). A machine built by the National Physical Laboratory is briefly described.

**Vickers Hardness and Compressive Strength.** D. S. Dugdale. (*J. Mech. Phys. Solids*, 1958, **6**, (2), 85–91). An empirical relationship of hardness to stress-strain curves is found. The Vickers test is shown to be insensitive to yield stresses corresponding to compression strains greater than 0·15.

**On the Problem of a Method for Measuring the Dynamic Hardness of Metals.** E. I. Timofeev and L. A. Urvantsov. (*Zavods. Lab.*, 1957, **23**, (11), 1365–1368). [In Russian]. A method for measuring dynamic hardness of metals is described based on the determination of the force of introduction of a tip, results obtained for several steels being compared with those found from determination of the energy of deformation. The method permitted the application of formulae used for calculating static hardness and a reliable comparison of hardness at various speeds of deformation to be made. A linear relationship between the static hardness and the ratio of dynamic to static hardness was found for normalized steels with static hardness values of 95–220 kg/mm².—S. K.

**A Hardness Tester for Small Loads.** H. Broschke. (*Microtecnic*, 1957, **11**, (5), 231–236). The Durimet device is described. It is a diamond indenter working with loads as low as 15 g.

**A Critical Commentary on Steel Selection: Ruling Section or Hardenability.** H. E. Arblaster. (*J. Austr. Inst. Met.*, 1957, **2**, Dec., 194–213). Steels B.S. En. 24 and SAE 4340 were tested by the U.S. Hardenability and British Ruling Section test. The end-quench test is discussed. Other mechanical properties are correlated with special reference to martensite.

**The Effect of Strain on Strain Aging.** C. J. Osborn. (*J. Aust. Inst. Met.*, 1957, **2**, Dec., 214–218). A low-carbon steel was examined at various temperatures by hardness tests. The time necessary for ageing and the activation energy of the process were independent of prior strains though the ageing rate in the early part of the process appeared to be increased by greater prior strain.

**Influence of Heat Treatment on the Ageing of Pure Iron After Quenching and Cold Work.** B. Migaud and J. Talbot. (*Compt. Rend.*, 1957, **245**, Dec. 16, 2282–2284). An explanation in terms of dislocations is advanced.

**The Role of Phosphorus in the Ageing of Normalised Steels.** T. V. Cherian and N. J. Wadia. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 83–93). Hardness and room temperature Izod tests were used to follow the ageing of normalized plain carbon steels at temperatures up to 600° C. The data indicated no significant ageing due to phosphorus. The minimum solubility of P in low carbon steels is deduced from the results of the Izod tests to be 0·29%.—B. C. W.

**The Effect of Various Heat Treatments on the Solidification Behaviour and the Specific Electrical Resistance of Soft, Unkilled Basic Bessemer Steel and Recarburized Pure Iron in Cold-Forming and During Quench—or Strain Ageing.** H. Schenck, E. Schmidtmann and H. Brandis. (*Arch. Eisenhütt.* 1957, **28**, Dec., 761–769). These effects have been studied in unkilled Bessemer steel with 0·02% C; 0·01% Si, 0·25% Mn; 0·029% P; 0·012% S and 0·0054% N, taken from the periphery, or with 0·05% C; 0·01% Si; 0·26% Mn, 0·05% P, 0·03% S and 0·0084% N, taken from the core of a 70 mm square billet, and in pure iron with ~ 0·009% C. Conclusions are drawn from the results with respect to the structure of the metals after that treatment. The experimental apparatus is described.—L. J. L.

**Brittle Fracture in Welded Ships: An Empirical Approach from Recent Experience.** J. Hodgson and G. M. Boyd. (*Inst. Nav. Arch.*, 1958, preprint, pp. 25). Failures are described and factors and requirements for a minimum standard of safety are set out. Steel requirements are then discussed and tests for notch toughness, and results obtained from materials after failure are given and considered.

**Brittleness in High-Manganese Stainless.** H. J. Beattie, jun. (*Met. Prog.*, 1958, **73**, Feb., 114–116). Brittleness in high-Mn, high-N austenitic stainless steels has been studied. Examination of the minor phases present in the steels containing 2% and 6% Mo showed the presence of $Cr_2N$ and a Laves phase based on $MoFe_2$.—B. G. B.

**A Tensile Study of the Brittle Behaviour of a Rimmed Structural Steel.** E. T. Wessel. (*Proc. A.S.T.M.*, 1956, **56**, 540–552, discussion 553–544). Notched and unnotched specimens were examined for brittle fracture down to −269° C. Plastic deformation preceeded fracture at all temperatures below 100° C. Increase of notch sharpness and of strain rate produced fracture at higher temperatures and lower stresses. Notched tensile data correlated with Charpy-V notched tests. A rimmed steel was used of the type associated with ship failures.

**A Contribution on the Use of Steels at High Stress Levels.** J. A. Garcia Poggio. (*Tecn. Met.*, 1957, **13**, Jan.–Feb., 1–43). [In Spanish]. This report is divided into three main sections. The first section discusses the problem of temper-brittleness and shows, by means of electron microscopy, that brittleness occurs at the beginning of the third stage of tempering just when the cementite is precipitating in films round the martensite needles. In the second section, the possible uses of the available national steels at high stress levels are discussed, and the ranges of use of some of these are defined. A study of experimental high-silicon (about 1·5%) steels is reported in the third section. Electron microscopy has shown that, in those steels showing less brittleness, the cementite precipitation has occurred in a non-cellular manner. The study is supported by physical data, property charts, Jominy curves, I.T.T. diagrams and microstructures. In conclusion, the author gives standards for the use of quality steels at high stress levels. (37 references).—F. S.

**Effect of Metallurgical Factors on Temper Brittleness.** S. M. Baranov. (*Metallovedenie Obrab. Met.*, 1956, Dec., 40–45). A correlation is established between method of processing and structure and temper-brittleness susceptibility and other properties. The cause is the presence of surface-active impurities including compounds of Si. The monoxide SiO dissolves in steel and has high surface activity and where it is present the metal has high hardenability, high stability in tempering, low impact value after tempering and temper-brittleness with lamellar cementite. Cr, Cr-Mn and Cr-Ni steels were examined deoxidized with Al and one control heat with Si, tempered, and impact tested. Results are tabulated. An explanation is advanced.

**Some Observations on 885° F Embrittlement.** G. F. Tisinai and C. H. Samans. (*Trans. Amer. Inst. Min. Met. Eng.*, 1957, **209**; *J. Met.*, 1957, **9**, Oct., Section 2, 1221–1226). The authors present new observations on 885°F hardening of 24–35%Cr-Fe alloys, and show an effect of preheat treatment that should contribute to a better understanding of the phenomenon. They also show that the hardening does not occur in electrolytic Cr, and that any long-range ordering type of reaction affecting any sizeable part of the volume is unlikely.—G. F.

**Studies on the Annealing Brittleness of Plain Carbon Steel.** T. Onishi. (*Tetsu to Hagane*, 1955, **41**, Sept., 1040–1042). [In Japanese]. For three rimmed and eleven killed steels (analyses given), impact values and Vickers hardnesses are shown as functions of austempering temperature, and the variations of impact value with different heat-treatments are given.—K. E. J.

**Influence of Some Alloying Elements on the Susceptibility of Steel to Temper Embrittlement.** M. L. Bernshtein. (*Metallovedenie Obrabot. Met.*, 1956, **2**, (9), 25–30). It is shown that tests should be made over a range of temperatures. 19 steels were tested by casting into 81 lb ingots and forging into 12 mm square bars. These were annealed and quenched and tempered to approximately constant hardness. Half were then tempered to develop brittleness and tested by impact. The effects of C, B, Al and V were examined. Elements are redistributed during treatment and accumulate at grain boundaries. New phases may appear.

**Better Tests for Brittle Fracture.** H. J. Nichols. (*Can. Metalw.*, 1957, **20**, Dec., 34, 36). A review of recent findings with sections on the selection of steel and on testing.

**On Hydrogen Brittleness of Steel. I.** I. Ohnishi, Y. Kikuta and K. Kawai. (*Osaka Univ., Fac. Eng. Techn. Rep.*, 1957, **7**, Mar., 151–158). The electrolytic charging cell is described and tensile, bend and impact test-pieces were used. The volume of hydrogen taken up was determined and the depth of the brittle layer measured. The reduction of strength varied with charging time and so with depth of penetration. Many small cracks penetrated this zone and stopped at the unattacked core. The effects were more marked in slow bend tests than on impact. Ageing for 4-5 days produced practically complete recovery in absence of pre-straining. With ~18% pre-strain there was practically no recovery of ductility.

**Arrest of Brittle Fractures in Wide Steel Plates.** R. J. Mosborg, W. J. Hall and W. H. Munse. (*Welding J.*, 1957, **36**, Sept., 393s–400s). Brittle fractures are initiated by driving a wedge into a notch at the edge of steel plate specimens. The fracture propagates across the specimen until it encounters the arresting device. It is found that under certain conditions, strakes of tough material will arrest a propagating brittle crack.—U. E.

**Abrasion of Metals, I. General Investigation in Abrasive Phenomena.** J. Shiba. (*Bull. Faculty Eng. Yokohama Nat. Univ.*, 1955, **4**, 1–9). Tests are described on various cast irons relating abrasion to coefficient of friction, work done, and pressure under various conditions.

**A Method of Solving the Stability and Rate of Stick-Slip Displacement of a Sliding Motion in the Phase Plane.** M. Mikeš. (*Czech. Heavy Ind.*, 1957, (1), 6–10). A graphical method is shown with application to heavy machine tools.

**Of Kinetic Friction Between Unlubricated Metallic Surfaces.** F. F. Ling and E. Saibel. (*Wear*, 1957, **1**, Dec., 167–172). A theory is proposed leading to a simple formulation of the coefficient of friction differing from that of Bowden and Tabor in that it is found to be the ratio of shear strength to yield pressure multiplied by a factor depending upon effects of load, velocity, temperature and other properties.

**Improving Strength of Structural Joints Using High-Tensile Steel Bolts.** K. W. Hang and R. S. Loubser. (*South African Mech. Eng.*, 1957, **7**, Aug., 1–12; discussion 13–25). Tests are described showing the greater frictional resistance obtainable by the use of higher tightening forces. Even with slip, the higher shear strength still gave improved joints. The high frictional force also makes load transfer more uniform between plates. Further tests are suggested.

**A Correlation of the Thermomagnetic and Domain Behaviour of a Single Crystal of**

**Silicon-Iron.** L. F. Bates, D. A. Christoffel, H. Clow and P. F. Davis. (*Proc. Roy. Soc.*, 1957, **243**, Dec. 24, 160–171).

**Electrical Sheet Steels for Power Transformers.** F. Brailsford. (*J.I.E.E.*, 1957, **3**, Nov., 569–575). Magnetization curves are shown for various alloys showing the effects of Si and other additions.

**New Magnetic Steel Claims Greater Efficiency.** (*Iron Age*, 1957, **180**, Oct. 31, 68–69). The implications of the development of a new "four-way" magnetic steel by Siemens-Halske Vacuumschmelze and Westinghouse Research Laboratories are described. The material is a silicon-iron sheet with a metallurgical structure that is cube-orientated. It requires less energy to achieve magnetization and reduces core losses; its electrical properties make it ideal for use in transformers, motors and other electrical devices. Details of the production process are not available, but the method involves a combination of heating and rolling and is commercially feasible.—

**Studies of the Magnetic Anisotropy Induced by Cold Rolling of Ferromagnetic Crystal Iron-Nickel Alloys.** S. Chikazumi, K. Suzuki and H. Iwata. (*J. Phys. Soc. Japan*, 1957, **12**, Nov., 1259–1276). Many domain patterns are shown.

**Study on Industrialisation of the MT Permanent Magnet, I. On Heat Treatment and Structure.** (*Tetsu to Hagane*, 1957, **43**, June, 647–652). [In Japanese]. Various conditions of heat treatment are investigated, and it is found that the best magnetic properties are obtained by quenching from 1200° C, holding for 20–30 min at the quenching temperature, oil-quenching (to promote formation of β-martensite), and tempering for 60–120 min at 300° C. The alloy must be annealed to make it machinable, but the magnetic properties deteriorate if the annealing temperature reaches 1000° C. **III. On Magnetic Properties and Industrial Applications.** (July, 726–732). The magnetic properties of this Fe-Al-C alloy are discussed, with special reference to instruments and other industrial applications which are described. The stability of the magnetic induction over long periods is important, and tests show that the alloy is more stable against demagnetization than chromium steel.—K. E. J.

**Machine for Wear Testing with Reciprocating Motion.** M. M. Khrushchov, R. M. Matveevsky and I. S. Bogatyrev. (*Zavods. Lab.*, 1957, **23**, (11), 1377–1379.) [In Russian]. Details are given of a new machine, type Kh6-B, for wear testing bushes and pins under reciprocating motion with a dry abrasive material in the gap and with a maximal load of 3000 kg. The maximal bush diameter is 31 mm and length 28 mm. Results obtained for type 45 steel (hardened using H.F. currents) with quartz sand as abrasive are presented. The test-pieces were weighed every 40,000 and the tests continued to 120,000 cycles. Similar tests were made with type-U8A steel specimens of different hardness showing the influence of this on wear. The machine is said to be suitable for abrasiveless, dry and lubricated tests.—S. K.

**Contribution to the Knowledge of Wear-Resistance of Bainite-Hardened Cast Iron.** R. G. Walzel and H. Ortner. (*Wear*, 1957, **1**, Dec., 183–195). [In German]. Two grades of flake-graphite iron after isothermal transformation were compared with specimens quenched and tempered to the same hardness, and with martensitic samples as quenched. The isothermal treatment in the lower hardening range (350° C) gives a favourable ratio between toughness and hardness and this showed considerably increased wear-resistance. The machine constructed for the tests is described and the importance of residual austenite and its transformation to martensite during wear is confirmed.

**Chemical Analysis of the Surface Layers of Metal Exposed to Different Wear Processes.** B. I. Kostetskii, N. L. Golego and P. K. Topekha. (*Vestnik Mashin.*, 1956, **36**, (10), 25–26). Tool steel with a foil-covered surface was used and the foil removed for analysis. Abrasion was carried out in air of 60% relative humidity at 20° C. The effect of atmospheric oxygen was determined, the $N_2$ being shown to be inactive, and sections of the abraded layers were examined and the disturbed metal analysed for oxygen content. The classification of wear processes previously advanced was confirmed.

**Equipment for Testing Friction Bearings and the Anti-Friction Properties of Materials.** I. Ya. Al'shits, L. I. Malykh and F. P. Snegovskii. (*Zavods. Lab.*, 1957, **23**, (11), 1380–1383). [In Russian]. Two machines for friction-bearing and materials friction testing, developed at the Central Research Institute of Technology and Machine Construction are described. The machines were designed to reproduce conditions approximating to service conditions, the test-pieces being in the form of inserts and ordinary works systems of lubricating being used. With these machines the friction coefficient, load-lifting capacity, running-in, wear (prolonged tests), lubricant temperature and other factors can be determined with different loading and friction rates.—S. K.

**A New Way to Select Wear-Resistant Materials.** J. R. Driear. (*Iron Age*, 1957, **180**, Nov. 21, 121–124). The method concerned involves assessing the wear conditions in the projected application and noting established practice for similar requirements. Considerations must involve load-bearing and self-lubrication needs; examples for various combinations of these are given.—D. L. C. P.

**Symposium on Exhaust Valve Life.** (*Proc. I.M.E., Auto. Div.*, 1955–56, (51). **Experimental Work on Exhaust Valve Life at Thornton Research Centre.** P. W. Bedale and R. Graham. (113–123). **Exhaust Valve Life in Small Industrial Gasoline Engines.** D. Downs. (124–132). **Some Metallurgical and Mechanical Considerations.** R. D. Mogford and F. A. Ball. (147–153). Wear, corrosion, mode of failure and the factors involved in these processes are reviewed.

**Reducing the Number of Inspection Tests for Hair-Line Cracks.** Yu. I. Vashchenko and R. I. Chemerinskaya. (*Stal'*, 1957, (12), 1119). Up to 20 to 25% of metal is wasted preparing step quench test pieces for tubes at the Pervouralsk (Urals) tube plant. Not one out of 5900 test pieces produced in one shop alone was rejected for hair cracks. Reference is made to work which shows that it is not essential to use step down test pieces for this purpose and that, in fact, they do not faithfully portray steel quality.—R. S.

**Using Water as a Liquid Vehicle in the Wet Continuous Method of Magnetic Particle Inspection.** V. Wiegand and E. H. Honerkamp. (*Nondestr. Test.*, 1958, **16**, Jan.–Feb., 28–30). The disadvantages of oil and the savings possible by the use of water are set out. The method is indicated and the results discussed.

**A New Electro-Magnetic Crack Detector.** Welding Supplies Ltd. (*Inspection Eng.*, 1958, **22**, Jan.–Feb., 20–21). A description of the O.K. Rapidomatic machine testing objects up to 500 mm × 70 mm dia at the rate of 600–1200 per h.

**A Machine for Making Magnetic Assays.** F. C. Dyer. (*Canad. Min. J.*, 1957, **78**, Oct., 92–93). A suspension of particles in a rotating and alternating field in a washing chamber is used.

**Some Magnetic Properties of Dilute Anisotropic Ferromagnetic Alloys.** W. Sucksmith. (*Brit. Elect. Allied Ind. Res. Assoc. Rep.*, 1956, N/T74, pp. 7). Fe precipitated out of solution in Cu is investigated.

**Magnetic Steel Is Doubly Orientated.** (*Steel*, 1957, **141**, Nov. 11, 131). A note on the development of "Cubex," a doubly-orientated or cube-orientated silicon-iron is given. Originated in Germany and developed by Westinghouse Elec. Corp., the steel has properties ideally suited for magnetic cores of transformers, motors and other electrical equipment. The crystal growth of the steel is carefully controlled during processing so that the cubic crystals are orientated and the steel can be magnetized in four directions. More work is required before the material can be offered for commercial use.—D. L. C. P.

**Magnetic Balance for Measuring the Magnetic Properties of Ferromagnetic and Paramagnetic Materials in the Range of Temperature up to 800° C.** J. Kozlowski and J. Siewierski. (*Prace Inst. Ministerstra Hutnictwa*, 1957, **9**, (6), 291–301).

**Study of the Anomalous Temperature Dependence of Initial Permeability and Magnetic After-Effects in Iron and Iron-Silicon Alloys at Temperatures between 300° and 700° C.** H. Fahlenbrach and G. Sommerkorn. (*Tech. Mitt. Krupp*, 1957, **15**, Dec., 161–164).

**The Brailsford Method for the Determination of Hysteresis Losses in Silicon Steels.** F. Marcos Villanueva. (*Rev. Cien. Apl.*, 1957, **11**, Nov.–Dec., 530–534). [In Spanish]. Results obtained by the Brailsford magnetometric method are critically compared with those obtained from the ballistic method. It is concluded that in spite of the limitations of the former technique it is to be preferred because of its simplicity. Its use to examine sheet of Spanish origin, heat-treated and/or cold-worked and heat-treated, is reported. Cold work increases the hysteresis losses, heat-treatment reduces them; heat-treatment at 750° C reduces the losses, compared with the initial condition, by about 40%.

**New Demonstration of the Hysteresis Loop in Iron.** H. C. Jensen. (*Am. J. Phys.*, 1957, **25**, Sept., 384–385).

**A Ferrometer for the Determination of the A.C. Magnetization Curve and the Iron Losses of Small Ferromagnetic Sheet Samples.** H. Blomberg and P. J. Karttunen. (*Proc. I.E.E.*, 1958, Jan., preprint 2482, pp. 10).

**Magnetic Susceptibility of the Alloy Pt,Fe between 20 and 900 Degrees Absolute.** J. Crangle. (*Nature*, 1958, **181**, Mar. 1, 644–645).

**The Effect of Manganese on the Magnetic Ageing of Low-Carbon Steel.** S. Hořejš. (*Hutník*, 1957, **7**, (12), 400–401). [In Czech]. On the basis of experiments it is shown that the requirement of Czechoslovak Standard Specification 12013, specifying 0·30% Mn as the upper limit in soft magnet steels, is inadequate. Magnetic ageing can be reduced considerably by increasing the Mn content to 0·40%. This does not result in an increase in the coercive force.—P. F.

**Energy Loss in Transformer Steel.** G. M. Leak. (*Research*, 1958, **9**, Feb., 56–60).

**Study of the Ageing of Pure Iron by Measuring Resistivity at Very Low Temperatures.** B. Migaud and M. Wintenberger. (*Compt. Rend.*, 1958, **246**, Jan. 20, 425–428). Resistivity is a sensitive indication of carbon precipitation from α-iron. Iron aged below 100° C was examined after quenching at 400°, 550°, 650° and 720° C. Mechanical properties were correlated.

**The Control of Flux Waveforms in Iron Testing by the Application of Feedback Amplifier Techniques.** J. McFarlane and M. J. Harris. (*Proc. I.E.E.*, 1958, Feb., preprint 2554, pp. 7).

**The Measurement of Wall Thickness of Metal from One Side Only, by the Direct Current Conduction Method.** J. S. Buchanan, F. W. Marsh and R. C. A. Thurston. (*Nondestr. Test.*, 1958, **16**, Jan.–Feb., 31–35). The theory is developed and the apparatus used is fully described with examples on the measurement of corrosion thinning, defects and lack of bonding.

**Studies on the Speed of Sound in Iron-Chromium-Carbon Alloys.** A. Fiedler. (*Arch. Eisenhütt.* 1957, **28**, Dec., 825–830). Sonic velocities have been measured by the impulse-echo method, using a precision water interferometer. A correlation was found to exist in these alloys between sound velocity and the carbon content and heat treatment.

**Automatic Ultrasonic Inspection.** H. W. Taylor. (*J. Brit. Inst. Radio Eng.*, 1957, **17**, Nov., 649–661). Factors limiting the use of manual methods are noted and a description of recent fully automatic equipment is given for the inspection of rolled bar and similar products.

**Ultrasonic Testing of Metal Components.** V. J. Manners. (*J. Austr. Inst. Met.*, 1957, **2**, Dec., 185–193). A review of the production and detection of ultrasonics and of the

appearance of flaws and difficulties in their detection. Transverse and surface waves are also considered.

**Ultrasonic Investigations on Cast Iron with Lamellar and Spheroidal Graphite Formation.** W. Patterson and E. Bodmer. (*Giesserei, Tech. Wiss.*, 1957, (17), 909–917). The experimental arrangement for carrying out ultrasonic investigations is described, together with the procedure. Investigations are described on 16 different specimens with different graphite formations. Multiple echo formation and echoes from the back face of the specimens are described for longitudinal and transverse waves. Wave velocities through the different types of cast iron are given and elastic constants determined.

**Ultrasonic Inspection of Castings.** J. Jarvis. (*Inspection Eng.*, 1958, **22**, Jan.–Feb., 15–19). Methods developed in a foundry are described. The derivation of tensile strength from the results is discussed.

**Non-Destructive Testing of Castings Using Ultrasonics.** G. Bierwirth. (*Giesserei*, 1957, **44**, Aug. 15, 477–485). The necessity of a non-destructive examination of the quality of castings is first described. The physical basis for the testing method using ultrasonic waves is given and the method of producing these waves and subsequently detecting them described in some detail. Measurements are described on single-phase and two-phase brass specimens, and the results compared. The damping coefficient is correlated with the Brinell hardness and the frequency of the ultrasonic waves. Measurements are described on cast-iron brake drums and compared directly with the texture and graphite distribution.—R. J. W.

**Measurement of the Size of Internal Flaws in Metal by an Ultrasonic Technique.** F. I. Ivanov and M. A. Akulin. (*Zavods. Lab.*, 1957, **23**, (3), 309–311). An accurate measurement of the size of flaws in turbine discs can be made by a method described. Direct measurement by sectioning revealed good agreement. The defect is scanned and the distance between the appearance and disappearance of the reflected signals is measured. Reference standards are not required. The method is not much affected by the sensitivity of the instrument used, but to detect fine flaws the scanning should first be carried out at maximum sensitivity.

**Methods of Ultrasonic Testing of Welds.** S. T. Nazarov and Yu. P. Panov. (*Zavods. Lab.*, 1957, **23**, (3), 305–308). A prismatic transducer is used for scanning welds and a nomogram is given for a 40° prism angle to give depth of flaw. The method of construction for other angles is shown. A standard with a groove of variable depth is described and the general operation of the apparatus explained.

**Use of the X-Ray Structural-Analysis Method for Studying Changes in the Surface Layer of Metal in Shot Peening.** N. A. Petrova, M. Ya. Shashkin and V. V. Latsh. (*Zavods. Lab.*, 1957, **23**, (11), 1372–1374). [In Russian]. Results obtained by X-ray structural analysis of shot-blasted surface layers of a Cr-Mo steel (0·33% C, 1·11% Cr, 0·35% Ni and 0·18% Mo) are presented and discussed. X-ray pictures were taken of the surfaces of all specimens and at increasing depth below the original surface after removing layers by electrolysis.—S. K.

**X-Ray Investigation of Structural Changes in the Surface Layer of Steel Treated by Machining.** O. N. Shivrin. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1956, (7), 736–739). [In Russian]. The processes of appearance of stresses in steel specimens of I, II and III orders and various cutting parameters and processes of the removal of the above stresses during annealing were studied.—V. G.

**Textural Stresses in Metals Measured by X-Ray.** (*N.B.S. Tech. Bull.*, 1957, **41**, Nov., 165–166). Steel specimens were evaluated in pearlite, spheroidized and decarburized forms.

**The Radiography of Welds.** A. Degembe. (*Prat. Sond.*, 1956, **10**, Oct., 162–164; Nov., 188–190; Dec., 202–206; 1958, **11**, Feb., 26–28; Mar., 48–51; Apr., 61–64; May, 81–86). This series of articles gives an outline of the techniques of radiography, the subjects dealt with including equipment, preparation of the sample, exposure and evaluation of the radiograph.—L. D. H.

**X-Ray Spectra and Interatomic Bonds in Alloys.** S. M. Karal'nik. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1956, (7), 815–819). [In Russian]. Some experimental facts in the field of X-ray absorption spectra of atoms of transitory states of metals and their alloys are discussed.—V. G.

**The Influence of Thermal and Mechanical Treatment on the Heat Factor of Dispersion of X-Rays by Solid Solutions.** V. A. Il'ina, V. A. Kritskaya, G. V. Kurdyumov and T. I. Stelletskaya. (*Izvest. Akad. Nauk, Seriya Fiz.*, 1956, (7), 723–728). [In Russian]. The influence of thermal treatment and deformation on interatomic bonding forces in crystals of iron alloyed with Cr, Ni, Mn and W was studied.—V. G.

**Radiography Technique Applied to Gamma Radiography.** A. Goëau. (*Centre Doc. Sidér. Circ.*, 1958, **5**, (1), 187–210). A detailed review of the use of gamma radiography is presented. Factors affecting the absorption of gamma rays by metals and the response of the film are discussed in detail. A number of graphs useful in calculating these factors and the exposure time are reproduced.—B. G. B.

**The Interaction Rates of Stopped Negative Muons in Iron and Copper.** A. M. Hillas, W. B. Gilboy and R. M. Tennent. (*Phil. Mag.*, 1958, **3**, Feb., 109–118).

**The Protons Emitted from Iron-54 and Iron-56 on Bombardment with 13·5 MeV Neutrons.** P. V. March and W. T. Morton. (*Phil. Mag.*, 1958, **3**, Feb., 143–151).

**Heat Capacity between 1·8° and 4·2° K of an Iron-Chromium Alloy in the Alpha and Sigma Phases.** F. E. Hoare and J. C. Matthews. (*Proc. Phys. Soc.*, 1958, **71**, Feb. 1, 220–224).

**Low Temperature Effects on Metals.** J. Waring. (*Austral. Eng.*, 1957, **50**, Nov. 7, 73–78). An account of effects on ferrous and non-ferrous metals of low-temperature environments. Effects on physical properties (tensile and impact values) are given, with notes on welds.

**The Behaviour of Heat-Resisting Steels at High Temperatures.** W. Stauffer. (*Escher-Wyss News*, 1957, **30**, (2), 17–32). Long-term creep tests and structures are described, also scaling by long periods of heating.

**Calculation of Optimum Intensity of Blackening in Gamma Radiation Methods of Detecting Defects.** A. N. Orlov. (*Detection of Defects in Metals by Gamma Radiation, U.S.S.R., Academy of Sciences, Symposium, Moscow*, 1955, 5–21). [In Russian]. A method is proposed for the theoretical calculation of the intensity of blackening of a photo-emulsion by exposing it to stable quanta in the simplest geometrical form. **Calculating the Effect of Dispersed Radiation on the Sensitivity of the Radiographic Method.** A. N. Orlov. (22–53). A general appraisal is made of the problem of calculating the sensitivity of a radiographic method and of determining the intensity of blackening of the film with dispersed radiation. In view of the absence of experimental data regarding the relationship between the spectral constitution of radiation and the thickness of the irradiated object, the most suitable theoretical data are used. **The Relationship Between the Capacity for Revealing Defects and the Intensity of Blackening When Steel is Irradiated by Co-60 Gamma Rays.** N. P. Grazhdankina and I. G. Fakidov. (54–60). The question of increasing the sensitivity of the photo-radiographic method has, until now, been based on the influence of geometric factors on sensitivity, i.e., on efforts to improve the revelation of defects by improving the definition. Efforts to improve sensitivity by improving contrast have not received sufficient attention. This article examines the relationship between contrast and intensity of blackening. **Exposure Graphs for the Irradiation of Steel by Gamma Rays of Co-60, Taking into Account Dispersed Radiation.** N. P. Grazhdankina and I. G. Fakidov. (61–69). The authors discuss the determination of the dispersion factor by means of characteristic curves of blackening of the film and describe the determination of inverse dispersion. **Selection of Energy of Gamma Radiation for Irradiating Metals.** S. T. Nazarov. (70–73). N. discusses certain formulae for calculating the sensitivity of films. He shows why it is necessary to select an isotope with the optimum energy of radiation and the greatest half-life. For irradiating steel, $^{60}$Co is used for thicknesses of 2 in to 8 in. $^{137}$Cs for $\frac{1}{2}$ in to 4 in and $^{192}$Ir $^{154}$Eu and others for $\frac{1}{2}$ in to 4 in thick material. **Determination of Defects in Corner Welds by Means of Gamma Radiation from Co-60, Ir-192 and Cs-137.** S. T. Nazarov and K. G. Goryacheva. (74–86). The inspection of corner joints by gamma radiography can be effected by means of isotopes having a wide range of energy from 0·42 mev (Ir) to 1·25 mev (Co). Gamma radiographic methods will reveal cracks in the tee, non-fusion discontinuities in the corner of the joint, blow holes and slag inclusions. Optimum angle of radiation is 45°. **Use of Cs-137 Gamma Rays for the Detection of Defects in Metals.** S. V. Rumyantsev. (87–93). $^{137}$Cs is a useful source of gamma rays for steel $\frac{1}{2}$ in to 4 in thick. To increase the sensitivity of the method of revealing minute defects in steel and other ferrous metals $\frac{1}{2}$ in to $1\frac{1}{2}$ in thick and in light metals, it is necessary to use radioactive isotopes with a gamma radiation energy of up to 0·3 to 0·45 mev ($^{154}$Eu, $^{92}$Ir, etc.). The weight of protective metal for Cs is less than that required for radioactive Co. **The Use of Radioactive Iridium for the Detection of Defects by Gamma-Radiography.** L. K. Tatochenko, S. V. Medvedev and V. S. Tokmakov. (94–99). It is shown that when not very thick metal objects are irradiated with $^{192}$Ir, higher quality photographs are obtained than with $^{60}$Co. **The Use of Radioactive Co-60 for Irradiating Welded Joints in Oil and Gas Pipe Lines.** M. P. Zheldak. (100–105). A method of using $^{60}$Co for gamma radiographic examination of large diameter electrically welded tubes is described. The unit consisting of tube, container and carriage is illustrated. **Increasing the Sensitivity of the Gamma Method By Using Filters for Dispersed Radiation and Limitation of the Exposed Area.** M. P. Zheldak. (106–108). Various combinations of filter materials for absorption of dispersed radiation are examined. The best was of iron 8 mm thick and lead 5 mm thick. The use of lead arresting plates to limit the area of exposure to gamma rays increases the sensitivity of the method. **An Examination of the Properties and Peculiarities of a Gamma Ray Detect Detector with an Ionised Counter.** A. A. Samokhvalov and I. G. Fakidov. (109–128). An improved Russian gamma "defectoscope" using a gamma counter instead of a film is described. The influence of various factors on the sensitivity is discussed. Defects in steel parts up to 12 in thick are revealed. **Sensitivity of the Method of Ionised Counters in Gamma Defect Detection.** A. N. Orlov. (129–142). As distinct from the photographic film, an ionized counter registers separate gamma quanta. This cuts down inspection time considerably. When evaluating the error in measuring the number of quanta, statistical fluctuations in the stream of gamma quanta must be taken into account. This article discusses the calculation of the sensitivity of the counter method.—R. S.

**Diffraction Chamber for X-Ray Examination of Chromium.** F. Sebilleau. (*Rech. Aéronau.*, 1957, July–Aug., 33–37). A set-up for the examination by reflexion of Cr and Co steels and other alloys is shown.

**Neutron Irradiation: Some Effects on Structural Materials.** W. D. Biggs. (*Iron Steel*, 1957, **30**, Dec., 625–628). The author describes the mechanism of radiation damage, and discusses the effects of neutron irradiation on the mechanical and corrosion properties of constructional steels. Low temperature properties, age hardening, and creep are the main properties considered.—G. F.

**Recent Uses of Radioactive Isotopes in Britain.** J. F. Cameron. (*Met. Prog.*, 1957, **71**, Jan., 103–108). The author describes the field of application of radioactive isotopes in

Britain. The subjects discussed include economic geology; ventilation problems; thickness gauges for use in process control and maintenance; research; gamma radiography; studies of the wear of surfaces; and radio-activation analysis.—G. F.

**Steels at Elevated Temperatures.** J. D. Murray. (*Iron Steel*, 1957, **30**, Oct., 493–495; Nov., 597–601). The author discusses the main essential properties required in high-temperature steels and then, taking creep resistance as the more important property, considers certain metallurgical aspects of creep-resisting steels. Finally, he describes methods by which design stresses are derived.

**Studies on the Mechanical Properties at Elevated Temperature of Timken 16-25-6. II.** (*Tetsu to Hagane*, 1955, **41**, Sept., 983–984). Tests were made on forged bars of 20 and 40 mm square section, and on specimens taken near the centre and near the corner of the larger bar. Hardness and creep rupture (650° C and 31·5 kg/mm²) data are given for specimens as forged and after solution-treatment at 1150° C followed by water-quenching. **IV.** T. Hasegawa and O. Ochiai. (1957, **43**, Aug., 812–817). [In Japanese]. Long-term creep-rupture properties at 600, 650 and 700° C, and short-term tensile properties at room and high temperatures were studied for the alloy when "hot-cold" worked at 700° C and reduced by 20% from the as-forged condition. These specimens were stronger at temperatures below 700° C than those differently heat-treated, and the ductility was satisfactory; the effects, however, decreased with increase of temperature and testing time. Test results also indicate that precipitation-hardened specimens have lower strength and higher ductility than solution-treated specimens.—K. E. J.

**Study on Heat-resistant Spring Steels.** Y. Motomiya. (*Tetsu to Hagane*, 1955, **41**, Sept., 976–978). [In Japanese]. Mechanical properties for various tempering temperatures are given for Cr-W-V and Cr-Mo-Si-V steels. The variation of permanent set with heating temperature is shown for the same steels (oil-quenched at 1060° and 1020° C, respectively, and air-cooled from 640° C).—K. E. J.

**Studies on the Mechanical Properties at Elevated Temperature of S 816. I.** T. Hasegawa. (*Tetsu to Hagane*, 1955, **41**, Sept., 984–986). [In Japanese]. Grain size, creep rupture and hardness data are given for specimens after solution treatment at 1150°, 1175°, 1200°, 1225° and 1250° C, in each case with and without ageing treatment.—K. E. J.

**Materials for Aircraft Structures Subjected to Kinetic Heating.** A. J. Murphy. (*J. Roy. Aeronaut. Soc.*, 1957, **61**, Oct., 653–666). Conditions met with are discussed and suitable steels and other alloys are tabulated and their properties given. Precipitation-hardening steels and their heat treatments are included.

**The Study of Heat-resisting Steel. XI.** E. Asano. (*Tetsu to Hagane*, 1957, **43**, July, 713–720). [In Japanese]. The effects of "warm-working" on 16–25–6 alloys containing Ti or B, and the variation of microstructure during precipitation of the worked material were studied. Warm-working was done at 650° C on an Amsler machine. Its effect was much more noticeable on the alloy containing B, where precipitation-hardening was pronounced only when it was warm-worked before ageing.—K. E. J.

**On the Mechanical Properties at Elevated Temperature and Resistance to Oxidation of Some Heat-resisting Steels of the Ferrite System.** S. Koshiba and T. Kuno. (*Tetsu to Hagane*, 1957, **43**, July, 711–713). [In Japanese]. Data are given for quenched and tempered hardness, high-temperature mechanical properties, rupture strength, creep limit and resistance to oxidation of seven ferritic heat-resisting steels (analyses given).—K. E. J.

**The High-Temperature Strength of Low-Alloy Steels.** S. Tsuchiya, S. Yamamoto and Y. Tanifuji. (*Tetsu to Hagane*, 1957, **43**, July, 703–710). [In Japanese]. Room- and high-temperature impact, tensile and creep properties of Cr-Mo-V, Ni-Cr-Mo, Ni-Mo-V, 1 Cr-Mo and 2·5 Cr-Mo steels are presented and compared. (15 references).—K. E. J.

**Diffusion in Metals.** (*Report of Colloquium at Eindhoven, Sept.* 1956. Published Philips Tech. Library, 1957, pp. 124). **Introduction to the Study of Diffusion.** A. D. Le Claire (1–17). Mathematical. **Diffusion of Radioactive Tracers in Solids.** K. Compaan and Y. Haven. (19–22). **Intergranular Diffusion and its Relation to Grain Boundary Structure.** P. Lacombe. (23–52). Non-ferrous examples are given. **Intergranular Autodiffusion in α-Iron.** C. Leymonie and P. Lacombe. (53–57). An account of research using $^{55}Fe$ and $^{59}Fe$ at 850° C in Armco, very pure, and fritted carbonyl irons is presented.

**The Influence of Nitrogen on Steel Surfaces.** F. Erdmann-Jesnitzer and G. Wieghardt. (*Werks. Korr.*, 1957, **8**, Nov., 669–673). The authors have investigated the effect of nitrogen on the tendency of finely-divided iron to ignite spontaneously in oxygen. Storage in pure nitrogen had no effect on the subsequent reaction between iron and oxygen. Consequently, the reduction in the tendency to spontaneous combustion observed after the storage of iron powder in commercial nitrogen must be due to the gradual formation of an oxide film on the surface of the iron particles through combination with the small amounts of oxygen present in the nitrogen as an impurity.—J. C. H.

**Toughness of Steel and Behaviour of Hydrogen in Steel. II. Numerical Consideration of Hydrogen Diffusion from Steel and Its Toughness.** S. Murayama. (*Tetsu to Hagane*, 1955, **41**, Sept., 1044–1047). [In Japanese]. Calculations of $H_2$ contents are made from diffusion considerations, and experimental values are given for residual $H_2$ in rails after cooling and after rolling, ingots after soaking, blooms after reheating, and in rail heads. Excellent agreement is shown between actual and calculated values for several air-cooled rails.—K. E. J.

**Investigation on Acid-Resistant High-Silicon Iron. II. Effects of Alloying Elements on Mechanical Properties, Corrosion Resistance and Shrinkage. I.** H. Sawamura, O. Tajima, K. Akamatsu and H. Muranaka. (*Tetsu to Hagane*, 1957, **43**, June, 652–657). [In Japanese]. The transverse strength was improved by the following (figures in parentheses are the optimum percentages): Ni (0·7), Co (0·3), Cr (0·6), Mo (3), W (0·8), V (0·09–0·5), Ti (0·3), Al (0·06) and Cu (0·3–3). Hardness was increased by Mn, P, Cr and Mo. Resistance to corrosion by sulphuric acid was increased by Mn, P, Ni, Co, Cr, V, Cu and As; that by hydrochloric acid by Mo and Ni. The shrinkage was decreased by adding all the elements tested except As. **2.** (July, 732–737). [In Japanese]. (14 references).—K. E. J.

**Effect of Manganese on the Properties of Cr-Mo Case-Hardening Steel.** K. Shinji and K. Kiyonaga. (*Tetsu to Hagane*, 1957, **43**, June, 642–646). [In Japanese]. The effects of Mn contents between 0·6 and 2·3% on Cr-Mn-Mo steel were investigated. At low quenching temperatures, Mn additions decreased the distortion ratio and increased the quenched hardness; the optimum addition was 1·6%. Additions increased the strength, though with some sacrifice in toughness, and improved abrasive properties in most cases.

**Is Cobalt Harmful in Stainless Steel?** J. R. Lane. (*Met. Prog.*, 1957, **72**, Dec., 86–87). Although Co in residual quantities in stainless steel is of no consequence in many applications, it could be objectionable in certain nuclear applications. Here neutron absorption may convert the element to cobalt-60, which is a dangerous radiation source.—G. F.

**Boron in Steel.** (*Mech. World*, 1957, **137**, Dec., 565–566). A brief account of the effects of B in alloy steels is given.

**Influence of Hot-Working Conditions on the High-Temperature Properties of Heat-Resisting Alloys.** J. F. Ewing and J. W. Freeman. (*Proc. A.S.T.M.*, 1956, **56**, 756–788). Austenitic alloys with 20% Ni, 20% Cr and 20% Co, balance iron, were examined. Hardness, rupture ductility and other properties were measured after various rolling cycles, and response to heat treatment was noted.

**Effect of Interstitial Atoms on the Self-Diffusion of Metal.** M. A. Krivoglaz and A. A. Smirnov. (*Problems of Metal Physics and Metallography, Metal Physics Lab. Ukrainian Acad. Sci.*, 1954, (5), 128–137). Small amounts of carbon greatly reduce the energy of activation for self-diffusion in γ-iron, a change of 4·5 atomic % of C changing the diffusion coefficient by a factor of $10^4$. The coefficients are calculated and a mathematical interpretation is attempted.

**Methods of Studying Diffusion by Means of Radioactive Isotopes.** J. Čádek and E. Janda. (*Hutn. Listy*, 1957, **12**, (11), 1008–1019). [In Czech]. Methods available for the study of diffusion in metals, ores and slags are discussed and the theoretical bases of individual methods are outlined. Particular attention is paid to Soviet developments involving measurements, or the utilization, of the absorption of radiation, as these do not necessitate sectioning of specimens or the exact measurement of small distances. Physical applications permitting the simultaneous determination of diffusion coefficients, heats of sublimation and thermodynamic activities are considered to be particularly useful.—P. F.

**Intercrystalline and Volume Diffusion of Manganese in Iron.** D. S. Kazacnovskii (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1956, (7), 94–102). [In Russian]. An investigation of the dependence of the character of frontal diffusion of Mn in iron on factors related to the method of smelting was carried out. Two types of iron were used; technical iron (produced in an O.H. furnace) and a specially prepared experimental iron in the preparation of which the possibility of contamination by impurities from scrap was excluded. The content of main elements in both types of iron was similar (the compositions of the individual melts used for experiments are given). Surface diffusion of Mn was carried out by cementation at 1200° and 1100° C for 10 h. In the technical iron, the diffusion front of Mn was even, while in the experimental iron the diffusion front was more advanced along the grain boundaries. This difference is explained by the presence in technical iron of surface-active impurities situated in boundary layers inhibiting the preferential diffusion of Mn along the grain boundaries.—V. G.

**Diffusion of Sulphur in Liquid Iron. II. Diffusion in Liquid Iron Saturated with Carbon.** Y. Kawai. (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1957, **9A**, Dec., 520–526). A tracer study from 1390–1560° C gives a coefficient of $2·9–3·6 \times 10^{-4}$ cm²/sec with a temperature dependency of $D = 2·8 \times 10^{-4} e^{(-3200/T)}$.

**Interphase Tension at the Slag-Iron Boundary and Surface Tension of the Molten System Manganous Oxide-Silica-Alumina.** Sh. M. Mikiashvili, A. M. Samarin and L. M. Taylev. (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1957, (4), 54–62). [In Russian]. Interphase tension at the boundary between slags of the above system and liquid iron were determined from the data obtained on the surface tension of the corresponding phases and the contact angle between them. The compositions of slags corresponded to those of deoxidation products of steel. It was shown that replacement of MnO with silica leads to a considerable decrease in surface tension, silica is surface active on the melt-gas surface. Alumina additions at a constant ratio of $MnO/SiO_2$ somewhat increase surface tension and at a constant MnO content increase it. Surface tensions of melts change little with temperature. It was shown that replacing MnO in slag by silica increases slag-metal interphase tension. The interphase tension also increases on replacement of MnO by alumina. MnO is surface-active on the iron-slag boundary. A decrease of interphase tension was noticed on replacement of silica by alumina. An addition of alumina to slag at a constant $MnO/SiO_2$ ratio somewhat increases the interphase tension. —V. G.

**Thermodynamic Principles of the Dissolution of Gases in Metals.** A. Krupkowski. (*Bull. Acad. Polonaise Sci.*, 1957, **5**, (6), 357–362). [In English].

**The Solubility of Hydrogen in Alloys.** H. Witte. (*Neue Hütte*, 1957, **2**, Dec., 749–756). Two methods of determining the solubility of $H_2$ in alloys are described. Standard entropy differences were determined from the dependence of solubility on temperature. They are approximately constant and are in good agreement with the notion that the $H_2$ atoms oscillate about their normal position in the interstitial mechanism.—L. J. L.

**Influence of Hydrogen in Steels.** A. Kohn. (*Mét. Constr. Mécan.*, 1956, **88**, Sept., 717–723). Factors influencing the $H_2$ content of steels and its effect on internal structure are considered. The formation of internal blowholes is discussed. (32 references).—B. G. B.

**The Use of Tritium for Study of the Behaviour of Hydrogen in Metals.** A. I. Chizhikov and V. K. Boyarshinov. (*Zavods. Lab.*, 1957, **23**, (1), 11–14). A 0·43% C steel and an Al alloy were examined. The degassed metal was loaded with $^3H$-enriched $H_2$ and radiographic studies were made. The rate of diffusion of tritium relative to hydrogen is estimated.

**The Influence of Carbon on the Solubility of Hydrogen in Liquid Iron-Carbon Alloys.** K. T. Kurochkin, P. E. Nizhel'skii and P. V. Umrikhin. (*Izvest. Akad. Nauk. Otdel. Tekn.*, 1957, (2), 19–26). [In Russian]. The influence of carbon on the solubility and the rate of a solution of $H_2$ in liquid Fe–C alloys at steadily increasing concentrations of carbon from 0·02 to 4·3% and above, as well as the influence of carbon on the residual content of $H_2$ in solid alloys after their saturation with $H_2$ in the liquid state were studied. A description of the apparatus and experimental procedure is given. It was found that: (1) The solubility of $H_2$ in liquid Fe–C alloys decreases with increasing carbon content up to 4·3%. (2) The content of $H_2$ in alloys, solidified in a $H_2$ atmosphere after the conclusion of the experiments, steadily increases up to 4·3% C. Above 4·3% C a sharp increase in the $H_2$ content was observed which is explained by the presence in these alloys of graphite. (3) The dependence of the solubility of $H_2$ in liquid Fe–C alloys on pressure obeys the square root law. (4) It increases with temperature. The temperature coefficient in the range 1450–1500° C depends on the carbon content and varies from 0·76cm³/100 g C (at 100°) at 1·2% C to 0·55 cm³/100 g. at 100°) at 4·3% C. (5) The thermal effect of solution of atomic H decreases with increasing carbon content up to 4·3%. This is probably due to the combination of a part of the iron with carbon into carbides. (6) The rate of solution of $H_2$ is independent of carbon content (other conditions equal).—V. G.

**The Influence of Vanadium on Oxygen Solubility in Iron-Carbon Melts.** R. A. Karasev, A. Yu. Polyakov and A. M. Samarin. (*Izvest. Akad. Nauk Otdel. Tekn.*, 1957, (2), 146–150). [In Russian].—V. G.

**The Solubility of Oxygen in Molten Iron Containing Manganese.** B. V. Linchevskii and A. A. Samarin. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (2), 9–18. [In Russian]. Oxidation of Mn dissolved in liquid iron was studied by establishing equilibrium conditions in the system melt—solid or liquid oxide phase—steam-hydrogen mixture at controlled temperatures of the metal and composition of the gaseous phase. It was established that, depending on the content of Mn in the liquid iron, the oxidation products of Mn which are liquid or solid solutions of the type $A$MnO(1-$A$)FeO steadily change their composition, becoming richer in manganese oxide. At 1565°C and a concentration above 1·8% Mn, pure MnO is formed. The dissociation pressure of solid MnO at 1600° C as well as the deoxidizing ability of Mn at 1565 and 1605° C were calculated. The influence of Mn on the activity coefficient of $O_2$ dissolved in Fe-Mn melts was studied. It was established that at Mn concentrations up to 0·5–0·6%, the activity coefficient varies within a range of 1·02–0·92; at Mn concentrations above 0·6% the activity coefficient is above unity and reaches 1·38 at 2·5% Mn.—V. G.

**A Study of the Diffusion of Boron and Carbon in Some Transition Metals.** G. V. Samsonov and V. P. Latysheva. (**Fiz. Met.*, 1956, **2**, (2), 309–319). Ti, Zr, Nb, Ta, Mo and W were studied.

**A Method of Determining the Coefficient of Diffusion of Hydrogen in Steel.** P. Bastien and P. Amiot. (*Rev. Mét.*, 1958, **55**, Jan., 24–38). A theoretical treatment is given of a new method of determining diffusion coefficients. Practical details are given of an experimental method for determining the diffusion of hydrogen in steel by means of the transfer of the overvoltage due to hydrogen, and by measurement of the amount of hydrogen diffusion. The effects of microstructure on diffusion were studied.—L. D. H.

**Rate of Diffusion of Hydrogen in Iron–Chromium Alloys.** P. V. Gel'd and R. A. Ryabov. (*Fiz. Mét. Metalloved.*, 1957, **5**, (1), 191–192). The influence of Cr on the rate of diffusion of $H_2$ is very peculiar. Up to 12% this influence is observed to lead to a sharp reduction in the rate and to an increase in the activation energy of the process. Thus if for pure iron, the activation energy, according to data furnished by some authors, amounts to 18.000 cal/mol, for an alloy with 12% Cr it exceeds 30.000 cal/mol. A further increase in Cr content to 28% practically does not change the rate of diffusion. The increase in the activation energy also ceases.

**A Study of the Diffusion of Sulphur in Steels.** A. Kohn. (*Rev. Mét.*, 1958, **55**, Mar., 265–274). An autoradiographic technique was used in which $^{35}S$ was employed. Some sulphur was shown to dissolve in austenite during annealing and then to precipitate at the austenitic grain boundaries. It appears that solubility of sulphur is markedly reduced by the presence of carbon. The rate of diffusion of sulphur in gamma iron is believed to be of the same order as that of carbon.—B. G. B.

**Diffusion of Niobium into Steel from the Gas Phase.** G. N. Dubinin. (**Zhur. Tekn. Fiz.*, 1952, **22**, (11), 1730–1740).

**Evidence from Autoradiography of the Preferential Autodiffusion of the Sub-boundaries in the Polygonisation of α-Iron.** P. Coulomb, C. Leymonie and P. Lacombe. (*Compt. Rend.*, 1958, **246**, Feb. 24, 1209–1212). Radioactive iron was diffused into pure iron at 700° C when the polygonization boundaries were disclosed, as shown by comparative etching studies.

**Variations in the Magnetic and Mechanical Properties of Iron Caused by Hydrogen Solution.** A Ferro and G. Montalenti. (**Il Nuovo Cimento*, 1957, Apr. 1, 842–852).

**Hydrogen Behaviour in Metals: A Factor in Selection of Metals for Equipment Fabrication.** G. P. K. Chu. (*Ind. Eng. Chem.*, 1958, **50**, May, 59A–60A). Effects on steel and a method for measuring solubility and diffusion behaviour are briefly described.

**Study of Hydrogen Brittleness in Iron.** G. Chaudron and L. Moreau. (**Metaux Corrosion-Usure*, 1943, **19**, 43–48). The effect of stress on degree of embrittlement in cold-reduced specimens is investigated.

**The Influence of Certain Elements on the Physical Properties of Steel.** G. Ramirez Estrella. (*First Nat. Congress Iron and Steel Industry* [*Mexico*], 1955, 165–169). Mn, P, Si, Cu, Cr, Ni, W, Ti and V are briefly reviewed.

**Influence of Carbon, Nickel, Cobalt, Tungsten and Molybdenum on Properties of 9·5% Tungsten Chromium Hot-working Tool Steel.** N. Yamanaka and K. Kusaka. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 46–52). [In Japanese]. Additions of Ni lowered the critical point and increased the hardenability. Co raised the critical point and Ms point, and improved tensile and impact properties. As C content was increased, hardenability and tensile strength increased and impact values decreased. Mo reduced the hardenability.

**Effect of Nickel on High-Carbon High-Chromium Die Steel.** S. Koshiba and S. Nagashima. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 43–46). [In Japanese]. To obtain high hardness with small distortion, quenching temperatures should be low. Additions of approx. 0·5% Ni were best to secure these.

**Observations on Hardening by Chromium.** L. Gascuel. (*PACT*, 1957, **11**, Oct., 430). Intercrystalline diffusion of Cr into the surface of iron or steel parts transforms that surface into an alloy of high Cr content. The depth of penetration depends on the type of base metal and on the method of treatment. No change in dimensions takes place unless the metal contains large amounts of impurities, particularly S and P. The treated surface shows superior corrosion and heat resisting properties.—B. P.

**Effect of Alloying Elements on Properties of Chrome–Nickel–Molybdenum–Copper Steel.** E. V. Zotova. (*Stal'*, 1958, (6), 550–556). Resistance to $H_2SO_4$ depends upon composition and on acid concentration. Cr reduces corrosion in 5–30% acid at 80° and Ni in 5–60% acid, as do Mo and Cu. Ti and Nb have no effect.—R.S.

**Effect of Copper on the Heat-Treating Characteristics of Medium Carbon Steel.** R. A. Grange, V. E. Lambert and J. J. Harrington. (*Trans. A.S.M.*, 1957, **51**, preprint 62, pp. 25). The effects of Cu up to 1·5% on hardenability, isothermal transformation, equilibrium transformation temperature, range of martensite formation and precipitation hardening of 0·45% C steel are determined.

**Developing Austenitic Stainless Steels with Low Nickel Content in the U.S.S.R.** N. F. Dubrov. (*Stal'*, 1958, (4), 356). Steels 1 Kh 17N497Az and 1Kh 17N398Az are suggested as replacements for 18–9 Cr-Ni steel. They contain 3–4% Ni and maintain austenitic structure at hot-working temperatures. Properties and analyses are given. Tensile strength is 20–25% higher than 18–9 steels, corrosion resistance to $HNO_3$, lactic and malic acids is good and addition of Ta and Nb reduces tendency to intergranular corrosion. Weldabilities are good.—R. S.

**Mechanical Properties of Some Ultra-High-Strength Steels.** I. V. Paisov and So Yum Ho. (*Metalloved. Obra. Met.*, 1958, Feb., 2–6). The steels 35 KhGNV2 and 45Kh N2SV2 are recommended for strength and toughness between + 20 to − 30° C. Compositions and properties of these and other steels are tabulated. The others were below 200 kg/mm² in tensile strength or had low impact values.

**Investigations of Reinforcing Steels with an Elastic Limit of 60 kg/mm². Determination of a "Tor-60" Steel.** Y. Saillard. (**Travaux*, 1953, Sept., 437–451). Measurements of adhesion to concrete are reported.

**The Problem of the Classification and Choice of Steels.** (*Prat. Soud.*, 1957, **11**, Mar., 44–46). The problem of simplifying the choice of steels for welded structures is discussed, with regard to the properties required and the conditions of service.

**New Stainless Steel to Beat Heat Barrier.** Firth-Vickers Stainless Steels, Ltd. (*Mat. Design Eng.*, 1958, **47**, May, 104–105). An account of the properties of FV520 Cr–Ni steel with Cu, Mo and Ti. Mechanical and corrosion-resisting properties are given.

**A 225,000 psi Commercial Cast Steel.** (*Mech. Eng.*, 1958, **80**, April, 70–71). A description is given of Wearpact, a complex low-alloy steel developed for the cast parts of mining equipment handling abrasive taconites. Properties are summarized and other possible uses are listed.—A. G.

**New Alloy Steels Beat Process Bugaboos.** D. B. Roach and A. M. Hall. (*Chem. Eng.*, 1958, **65**, May 19, 180, 182, 184). New grades are briefly reviewed with special attention to corrosion. (June 2, 134, 136, 138). Precipitation-hardening steels are tabulated and their properties reviewed.

**Stainless Steels with Improved Mechanical Characteristics.** M. R. Castro. (*Bull. Cercle Etudes Mét.*, 1957, **7**, Dec., 227–258). A general survey is made of the known methods of improving the physical properties of various types of stainless steel. (44 refs.)

**Boron Steels.** A. Clerc. (*Métaux Corr. Ind.*, 1957, **32**, Nov., 409–435). This is a comprehensive survey of the present state of knowledge as shown in the literature, con-

cerning the effects of boron in steel. The subjects dealt with include the manufacture of boron steels, the determination of boron, and the properties of various types of steel containing boron. A section discussing the influence of boron on hardenability is included. (65 ref.).—L. D. H.

**Corrosion-Resisting Steels.** V. Kovac. (*Zaštita Mat.*, 1956, **4**, Feb., 45–49). The Cr–Ni steels are reviewed with the structures and heat-treatments, forms of corrosion are described and the effects of heat, cold work, welding brazing and pickling. Maintenance of equipment is also considered.

**Corrosion-Resisting Steels for High Temperatures.** D. Dančevic. (*Zaštita Mat.*, 1955, **3**, May, 165, 168). The effects of Ti on austenite stabilization are noted.

## METALLOGRAPHY

**The Standardisation of Photographic Exposures in Metallurgical Microscopy.** L. E. Samuels, T. O. Mulhearn, and R. M. Robb. (*Metallurgia*, 1958, **57**, April, 207–212). A method for standardising exposure is described in which the microscope is calibrated for each standard optical combination and magnification with a reference alloy and standard illumination. Exposure factors are determined for other alloy groups and changes in illumination.—A. G.

**Diamond Abrasives in Metallographic Polishing.** L. E. Samuels. (*Journal of the B.S.C.R.A.*, 1957, Dec., reprint. pp. 5). With proper use the polish obtained is better than that obtained with conventional abrasives and the cost is negligible.

**Chemical Polishing of Metals.** L. Krošar. (*Zaštita Mat.*, 1956, **4**, Jan., 12–15). Non-ferrous mainly.

**A Method for the Etching of Metals by Gas Ion Bombardment.** J. B. Newkirk and W. G. Martin. (*Trans. A. S. M.*, 1957, **50**, Preprint 8, pp. 13). Metallographic specimens were etched more rapidly and with less heating of specimens when krypton was used as the etching agent and a magnetic field applied in the ionization chamber.—E. E. W.

**A New Method for Revealing Austenite Grain Boundaries by Corrosive Gases.** M. Someno and M. Kawakami. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 33–37). [In Japanese]. A polished steel surface maintained at high temperature in an inert atmosphere containing HCl or chlorine shows deep etching at the boundaries within a few minutes.—K. E. J.

**Microstructure of Surface Layer Formed on Steel Hard Faced by Electrosparking.** V. A. Belyanin. (*Metallov. Obra. Met.*, 1958, Jan., 55–57). Alkaline ferricyanide solution was found to be a suitable etching agent for the white layer formed with ferro-chrome or carbides. The ordinary agents do not etch this coating and this is shown not to be due to the presence of nitride.

**The Determination of Non-Metallic Inclusions in Steel.** M. M. Shapiro. (**The Metallurgy and Heat Treatment of Steel and Cast Iron; a Handbook*, 1957, Chapter 10, 112–116). A review of methods.

**Accelerated Method for Isolating Carbide Phase in Steel.** O. Spiridonova and T. I. Bezuglova. (*Zavods. Lab.*, 1957, **23**, (12), 1412–1413). A simplified electrolytic method is described and compared with an earlier process with which the agreement was good.

**Analysis of Carbide Phases in Steel.** N. M. Popova. (**The Metallurgy and Heat Treatment of Steel and Cast Iron; a Handbook*, 1957, Chapter 11, 116–118). Proposed methods of separation and chemical and X-ray analytical methods are outlined.

**Electrolytic Extraction of Carbides from Carbon Steel.** R. W. Gurry, J. Christakos and C. D. Stricker. (*Trans. A. S. M.*, 1957, **50**, Preprint 4, pp. 34). A simple effective apparatus and technique are described. The method results in less decomposition of carbide and its performance is demonstrated on steels tempered over a range of temperatures.

**The Problem of Sulphide Inclusions in Cast Steels.** D. K. Butakov. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 154–159). From experimental results it may be concluded that in order to overcome the resistance of the granulated structure caused by sulphides, it is necessary to reduce to the utmost the content of sulphur in the molten steel, to reduce the solubility of sulphur in austenite by changing the physical and chemical properties of the sulphide phase by introducing into the steel elements such as to Mn and Al, and by suitable thermal treatment to eliminate the "secondary" sulphides from the grain boundaries, or bring about their coalescence.—L. H.

**On the Intergranular Localisation of Sulphur in Pure Iron Charged with Cathodic Hydrogen in the Presence of Sodium Sulphide.** S. Besnard and J. Talbot. (*Compt. Rend.*, 1958, **246**, Jan. 27, 607–608). Previous experiments are repeated using radioactive $^{35}S$ and penetration at the grain boundaries is confirmed.

**The Influence of Thermal Treatment on the Distribution of Calcium in Ferro-Silicon.** I. N. Strukov, M. A. Shumilov and P. V. Gel'd. (*Fiz. Met. Metalloved.*, 1957, **5** (1), 188–189). Microscopical investigation by autoradiogram has shown that in hardened specimens the diffusion of Ca is to a considerable extent non-uniform, being concentrated mainly along the crystalline boundaries. Subsequent hardening of the annealed specimens from 1000° leads again to a preferential separation of Ca in the intercrystalline zone, its elimination from which is increased by repeated stabilizing annealing.—L. H.

**Some Aspects of the Morphology and Chemistry of Lead in Leaded High Sulphur Steels.** J. W. Thurman, E. J. Paliwoda and E. J. Duwell. (*Trans. A. S. M.*, 1957, **50**, *Preprint* 50, pp. 28). Microradiographical and metallurgical methods were used to determine the distribution of lead in both the as-cast and hot-rolled conditions. Lead occurs largely in the elemental condition together with manganese sulphide in the interdendritic regions.—E. E. W.

**Malleable Iron Microstructures Effect and Cause.** (*Mod. Castings*, 1958, **33**, April, 100–110). A number of photomicrographs of malleable irons are presented and an attempt is made to explain the causes of the observed effects.—A. G.

**On the Autoradiographic and Micrographic Detection of Former $\gamma$-Boundaries in Iron.** P. Coulomb. (*Compt. Rend.*, 1958, **246**, Mar. 3, 1421–1424). Chemical etching, heat corrosion and intergranular diffusion are used to detect the boundaries. Autoradiographs are compared with sections etched with *m*-nitrobenzenesulphonic acid in alcohol.

**The Formation of Proeutectoid Ferrite in Plain Carbon Steels.** C. A. Dubé, H. I. Aaronson and R. F. Mehl. (*Rev. Mét.*, 1958, **55**, Mar., 201–210). The structures of proeutectoid ferrite in plain carbon steels are classified into 5 major types. The effects of isothermal reaction temperature and time, carbon content, austenite grain size and of the competitive formation of pearlite upon the development of the structures are considered in detail.—B. G. B.

**Transformation Structures in Hypoeutectoid Alloy Steels.** W. C. Hagel and M. N. Ruoff. (*Trans. A. S. M.*, 1957, **50**, Preprint 25, pp. 27). Detailed microscopical observations were made of the morphological aspects of both isothermal and cooling transformations in laboratory Ni–Mo, Cr–Mo–V and Ni–Cr–Mo steels containing 0·3% C. Transformation curves are given. The resultant structures are more continuous and intermixed than existing classifications indicate. The dominating effects under different conditions are indicated.—E. E. W.

**Some Transformation Structures of Austenitic Manganese Steels.** R. Castro and P. Garnier. (*Rev. Mét.*, 1958, **55**, Jan., 17–23). The transformation structures of three austenitic Mn steels have been examined with particular reference to the upper part of the transformation range. The carbon contents of the steels varied from 1 to 1·25%, and the Mg from 12% to nearly 16%, the Mn/C ratios lying between 15 and 10. Some practical conclusions are drawn regarding the heat treatment of these steels.—L. D. H.

**Influence of the Rate of Heating for Hardening, on the Non-uniform Concentration of Carbon in Austenite.** A. G. Spektor. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 142–149). Short induction heating for hardening is practised more and more. The shortening of the heating time is accompanied by an increase in temperature. This process should be no obstacle to attaining the required stage of solution of the carbide phase since the reduction in time is compensated by an increase in the rate of diffusion and of phase transformation. It has, however, been evident in practice that the shortening of the time of heating, for any average composition, makes solution from the carbide phase of the alloy elements and of carbon, less uniform. The article investigates this fact by determining the gradient of carbon concentration and computing the average non-uniformity of diffusion.—L. H.

**On the Influence of Tempering on Graphitisation.** K. P. Bunin and E. N. Pogrebnoi. (*Lit. Proizv.*, 1955, (8), 25–27). [In Russian]. Usually, graphitization during the annealing of steel at subcritical temperatures occurs immediately after hardening, but it is essential to investigate graphitization under such conditions that, during annealing, the steel becomes first austenitic, i.e. when heated above the eutectic point, remains in this condition for some time, and only later becomes graphitic at subcritical temperatures. This is the problem investigated, and the findings show that the main cause of the increase in the number of graphitic inclusions and of the speeding up of the graphitization process in steel at subcritical temperatures after preliminary hardening, resides in the damage arising from microscopical fractures during hardening and from the distortion of the metallic matrix.—L. H.

**On Graphite Formation in Magnesium Iron.** K. I. Vashchenko and L. M. Sofroni. (*Lit. Proizv.*, 1955, (11), 17–25). [In Russian]. In treating cast iron with Mg, owing to the rapid cooling, a disturbance occurs in the graphitization process in the fluid state (in the eutectic temperature region) as shown by the well known brittleness of Mg iron solidifying with the white structure.

Slightly below the eutectic temperature (it may also be after formation of the first crystals) the cementite, due to the high silicon content, spreads, as if there were an automatic annealing process in the iron.

**The Nucleation of Graphite During Decomposition of Cementite.** E. G. Haney and M. F. Hawkes. (*Trans.A.F.S.*, 1956, **64**, 515–524). White cast iron after rolling, peening or twisting before graphitizing, was treated isothermally and the number of graphite nodules per mm$^2$ were counted. Dependence upon rolling temperature, per cent reduction and reaction temperature was studied. The number is related to prior plastic deformation (and inversely to deformation temperature) and the effect can be annealed out. Shot peening produces a still greater count. Residual stresses are proposed as the explanation of variations in nucleating behaviour.

**Mechanism of Influence of Preliminary Quenching of White Cast Iron on the Formation of Graphite Nuclei.** A. F. Landa and V. D. Yakhnina. (*Metallov. Obrab. Met.*, 1956, (12), 46–50). Investigations show that there is reason to believe that the graphite nuclei matrix is formed from cementite. Newly developed methods of accelerated annealing of white cast iron must be used to reduce the stability of the cementite phase. If the cementite is, however, not stable enough, its breakdown may be limited and this would adversely affect the form of graphite inclusions.—R. S.

**Influence of Sulphur on the Graphitic Structure of Magnesium Iron.** A. D. Ushakov (*Lit. Proizv.*, 1955, (9), 19–20). [In Russian]. The formation of appreciable ferritic layers around graphitic inclusions shows the high rate of diffusion of carbon in the iron, in presence of S.

This essential condition may also lead to change in the surface tension of the melt with alterations in the S content.—L. H.

**Influence of Alloy Elements on the Kinetics of Graphitisation of White Iron.** M. A. Krishtal. (*Metallov. Obra. Met.*, 1955, (4), 24–27). The speed of diffusion of iron atoms in austenite can be calculated from the coefficient of diffusion of vacancies $\left(D_{Fe}^{\gamma}\right)$, the value of which has been determined between 920–1050°, (in *Dokl. Sc. Academy*, 1954, **99**, (6), 983).

The speed of graphitisation can then be calculated from

$$D_{Fe}^{\gamma} = A_0 - \frac{Q}{RT}$$

where A is a frequency factor,
Q, the activation energy,
R, the gas constant,
and T is absolute temperature.

**Effect of Tungsten on the Kinetics of the Process of Graphitisation of White Cast Iron.** M. A. Krishtal. (*Metallov. Obra. Met.*, 1956, (5), 17–18). Research has shown that the rate of graphitisation of white iron is usually limited by the speed of displacement of the iron atoms in the austenite due to the diffusion of the vacant sites, which is less than the speed of diffusion of carbon. When the W content is increased, the speed of self-diffusion of iron is markedly increased while the speed of diffusion of carbon is retarded. Some tests with a cast iron containing 4% C, 1·2% Si and 0·8 and 1·0% W to determine the speeds of diffusion of iron and carbon are described.—B. S.

**Investigation with the Electron Microscope of the Internal Grain Mosaic Structure of Austenite.** E. I. Kvashnina. (*Metallov. Obra. Met.*, 1955, (5), 15–17). Pictures are reproduced × 7500 showing the fine internal structure of austenite distinct from the internal layers along the boundaries.

Changes in structure have been recorded after intervals between 8 and 14 h.—L. H.

**Effect of Hot Working on Growth Characteristics of Austenite Grains in Steel.** Y. Masuko. (*Tetsu-to-Hagane*, 1957, **43**, Oct., 1122–1127). Work on medium-carbon and medium-carbon Cr-Mo steels shows that hot working lowers the coarsening temperature of austenite, and annealing after forging lowers it considerably. These effects were more noticeable in duplex-grained steel, but were less than that of ingot size. These effects, and also the occurrence of duplex grains, are attributed to the behaviour of AlN. Differences of grain size and grain growth characteristics between a ladle sample and the finished product are mainly caused by teeming conditions.—K. E. J.

**Studies on Duplex-Grain Structures of Austenite. I. Effect of Duplex-Grain on Properties of Steel. Part 2.** Y. Masuko. (*Tetsu-to-Hagane*, 1958, **44**, Jan., 28–32). [In Japanese]. (35 references).—K. E. J.

**Relations in the Orientation of Unstable γ-Phase and the α-Phase Resulting from its Plastic Deformations: Conditions of Annealing of the α-Phase.** P. Bastien and R. Margerand. (*Compt. Rend.*, 1958, **246**, June 9, 3238–3240). Confirming a previous note, micrographic and X-ray studies show a relationship between the phases. A method of etching with oxalic acid stains the α-phase grey while the γ-phase remains white, the γ-phase is much deformed and α- and γ- much intermingled. At × 2350 corrosion figures can be seen. Annealed α-phase gives an unorientated austenite. X-rays give similar results. The structures are described and illustrated.

**The Identity of the Tau- and Y-Phases from Austenitic Steels.** O. Knop. (*Metallurgia*, 1958, **57**, Mar., 137–138). A letter. Tau, it was suggested, was $Ti_2S$ while *Y* appeared to be a nitride. Crystal structure is discussed. (Reply). J. F. Brown, W. D. Clark and A. Parker (138). Identity of diffraction patterns is agreed. Single crystals have not been obtained for certain classification. $Ti_2S$ has been reported, but its pattern is quite different.

**Classification of Precipitation Systems.** R. O. Williams. (*Trans. A. S. M.*, 1957, **50**, preprint 13, pp. 13). Degree of order in the matrix and precipitate, shape of particles formed and degree of complexity of nucleation are three characteristics proposed for classifying all precipitation systems because they are all intimately associated with kinetics and physical properties.—E. E. W.

**The Ferromagnetic Phase in Heat-resisting Steels of Type 14-14.** V. Z. Tseitlin. (*Fiz. Met. Metalloved.*, 1957 **5**, (1), 37–43). The ferromagnetic α-phase appears preferentially in the structure of heat-resisting steels of type 14-14. It develops there not only as a consequence of ageing, but also in tempering after hardening, and it ceases under well-defined conditions. It appears along the boundaries and around the separated carbide grains and is connected by the diffusion process with the formation of carbides. The occurrence of the ferromagnetic α-phase corresponds to a considerable reduction in the heat-resisting properties during static cycle stresses. Hence in heat treatment it is necessary to choose that temperature and duration of treatment in which the α-phase will have time to disappear to a considerable extent.—L. H.

**A Contribution to the Study of the Iron–Carbon Equilibrium Diagram: The Solubility of Carbon in Pure Iron.** P. Gendrel and L. Jacqué. (*Compt. Rend.*, 1958, **246**, Jan. 27, 596–599). The limits of maximum solubility of C in γ-iron have been determined for specimens of different purities from the measurement of rates of reaction. Solubility decreases with increasing purity of the iron, as does that of gases.

**Phase Relationship in Austenitic Cr–Mn–C–N Stainless Steels.** Chi-Mei Hsiao and E. J. Dulis. (*Trans. A. S. M.*, 1958, **50**, Preprint 29, pp. 44). The stable austenite region in steel containing 0·10/0·80% C, 5/28% Mn, 12/28% Cr and 0·10/0·80% N has been determined. At 2100° F the minimum amount of C plus N required for a completely austenitic structure increases with increasing amounts of Cr, according to the expression

$$C + N = 0{\cdot}78\,(Cr - 12{\cdot}5)$$

when the Mn is between 5 and 14%. The effect of different treatments on the microstructure is discussed.—E. E. W.

**Phase Relationships in the Fe–Cr–Ni–N System.** G. F. Tisinai and C. H. Samans. (*Trans. A.S.M.*, [1959], **51**, preprint 71, pp. 27). Study of 82 alloys, 59 prepared by powder methods, defined the austenite–austenite plus ferrite limits in the range 21–33% Cr with up to 1% N and 20% Ni. At 2200° F these are straight lines with 0·025% N equivalent to 1% Ni and independent of Cr, but as Cr is increased more N or Ni must be added to produce a completely austenitic alloy. Changes down to 1300° F were followed metallographically and by X-rays. Sigma phase was detected only in 33% Cr alloys below 1600–1700° F depending on carbon content.

**Solidus, Subsolidus and Subdissociation Phase Equilibria in the System Fe–Al–O.** L. M. Atlas and W. K. Sumida. (*J. Am. Ceram. Soc.*, 1958, **41**, May, 150–160).

**Nature of the Interaction between Titanium Boride and the Iron-Group Metals.** G. V. Samsonov. (*Metallov. Obra. Met.*, 1958, (1), 35–38). The phase diagram for $TiB_2$–Fe, among others, is constructed. The value of $TiB_2$ for hard metal compositions is considered.

## CORROSION

**The Electrochemical Corrosion of Metals.** T. Sneck. (*Tek. Kemian*, 1958, (7), 183–188). A review of the mechanism of corrosion with notes on local elements, pH-potential diagrams and changes produced by inhibitors and the limitations of single electrode potential measurements for prediction of corrosive effect on the action of inhibitors.

**The Uses of Measurements of Oxygen Depolarization Currents in Corrosion and Other Fields.** F. Tödt. (*Zaštita Mat.*, 1956, **4**, Feb., 36–44).

**The Precipitation of Magnetite at Substructure Boundaries of Oxygen-rich Ferrous Oxide.** J. Paidassi. (*Acta met.*, 1958, **6**, Jan., 69–71). [In French]. Magnetite is precipitated at the boundaries of subgrains during the cooling of oxygen-rich wustite formed in steam at 1000° C. This observation is used to explain the duplex structure of scale formed in air.—A. D. H.

**The Kinetics of the Oxidation of Iron in Air at 700–1250° C.** J. Paidassi. (*Acta Met.*, 1958, **6**, March, 184–194). [In French]. Under isothermal conditions the oxidation curve of iron is generally parabolic and three continuous layers of $Fe_2O_3$, $Fe_3O_4$ and FeO whose relative thicknesses are 1 : 4 : 95 are formed. The heat of activation is 40·5 kg. cal./mol. If the scales are non-adherent, the phase constitution of the layer is modified.

**On the Constitution and Morphology of the Surface Oxidation Film on Iron in Steam at High Temperatures.** J. Paidassi and D. Fuller. (*Compt. Rend.*, 1958, **246**, Jan. 27, 604–607). Armco and Westinghouse "Puron" irons were examined at 700–1250° C. The samples were heated in an evacuated tube furnace in a current of moist A (3 cm/sec.) and cooled in the furnace. Adhesion varies with the atmosphere used; the layer is of FeO except between 900–920° or when heated for more than 6 h when an outer discontinuous layer of $Fe_3O_4$ appears. At 650–750° needle-like forms appear, apparently by martensitic transformation on cooling. The FeO-water interface has a jagged appearance, the depressions corresponding to the grain boundaries. Structures are shown.

**Investigation of High-temperature Oxidation of Some Iron–Tungsten Alloys.** Yu. D. Kozmanov. (*Fiz. Met. Metalloved.*, 1957, **5**, (1), 74–81). The aim of this investigation was the study of the influence of additions of W on the heat-resistance of iron and the elucidation of the oxidation mechanism of the alloys of iron with tungsten. The results confirmed that additions of up to 16% W impart high heat-resisting properties, and the purer the iron, the more effective the first 5% of W are. The Fe—W alloy increases in heat-resisting properties mostly between 700–800°. At 1100° the oxidisability of the alloy (up to 16%) is little different from that of iron alone. During the process of oxidation, the secondary reactions between the oxides of Fe and W play an important rôle.—L. H.

**Oxidation of Binary Alloys at Elevated Temperatures.** J. Moreau. (*Rev. Nickel*, 1956, **22**, Oct-Nov.-Dec., 79–86). The author discusses theoretical and practical aspects of the oxydation of Fe–Ni, Fe–Cr and Ni–Cr alloys. Oxygen affinity, reactions between the oxides formed, internal oxydation and diffusion rates are dealt with.—R. P.

**Determination of the Thickness and Constitution of Oxide Films on Tin and Tinplate.** S. C. Britton and K. Bright. (*Métaux Corr. Ind.*, 1957, **32**, Nov., 436–442). Two methods are described for examining the oxide films formed in tin and tinplate. In the first, the reducible oxide is determined by cathodic reduction. In the second, the film is removed by the action of Hg and examined radiographically. The results of the two examinations established that the film formed by oxidation in air consists of stannous oxide, and is probably of the order of 20–60 Å in thickness, according to the time of exposure, and assuming a dry atmosphere.—L. D. H.

**A New Cabinet for Corrosion Testing.** P. Živanovic. (*Zaštita Mat.*, 1955, **3**, July, 232–235). Apparatus for simulating all climatic conditions for the testing of metals and other materials is described.

**Electrochemical Method of Evaluating the Protective Power of a Paint Against Corrosion.** P. Debouté. (*Peint. Pig. Ver.*, 1958, **34**, Feb., 68–72). After pointing out that chemical corrosion tests cannot always indicate the initiation of corrosion of a metallic surface coated with paint, the author describes a method based on the measurement of changes in the electrical conductivity of a system platinum electrode–electrolyte–metallic sample-paint. The electrolyte used was a 3% solution of potassium sulphate, having a

pH value of 7·0; the electrodes were of Al alloy, treated with various paint coatings. It was found that a sharp change in conductivity was associated with deterioration of the protective coating.—L. D. H.

**The Influence of Inhibitors on the Relation between Adsorbed and Evolved Hydrogen in the Corrosion of Iron in an Acid Medium.** G. Bolognesi and L. Felloni. (*Corros. et Anticorros.*, 1957, **5**, July-Aug., 210–215). The effect has been investigated of three typical inhibitors on the rate of dissolution of Armco iron in N HCl. The amount of $H_2$ evolved was measured, and the dissolved iron was determined colorimetrically. It is concluded that inhibiting power cannot be correctly assessed by measuring the amount of $H_2$ evolved; the choice of inhibitor should be governed by $H_2$ adsorption. (19 ref.).

**On Surface Layers on Cast Alloys, Especially Cast Iron.** A. Königer. (*Giesserei, Tech. Wiss.*, 1957, (17), July, 925–934). The field is first reviewed historically. The electrochemical basis for corrosion processes is discussed in relation to the quantum theory. The formation and composition of different oxide layers is described together with the applicability of short-duration testing. The theoretical basis for passivating cast alloys is given. The role of trace elements is considered in detail and their effects on passivation described.

**Fundamentals of Electrode Processes in Corrosion.** M. Stern. (*Corrosion*, 1957, **13**, Nov., 775–782). Polarization diagrams are used to explain the principal factors affecting electrochemical corrosion. The concepts of "exchange current," "activation polarization" and "concentration polarization" are introduced to clarify the way in which electrode kinetics can be applied to actual corrosion problems. Many early classical experiments and some important recent observations in the corrosion field are discussed. Reference is made to the effects of solution velocity, galvanic couples and the composition of metal and environment on the corrosion rate.—J. F. S.

**An Electrographic Investigation of the Nature of Passive Films.** V. P. Batrakov and I. A. Ponizovskaya. (*Izvest. Akad. Nauk, Seriya, Fiz.*, 1957, (7), 830–833). [In Russian]. Classic cases of passivity of carbon steels St. 10, St. 45, U8 and low alloy steel 30KhGSA, steel with 50% Cr, stainless steels EI457, EI268, EI401 and 1Kh18N9T, as well as technical Al in solutions of $HNO_3$, $Na_2Cr_2O_7$ and $K_2Cr_2O_7$ were studied using electronographic methods. The results obtained are given in the form of tables.—V. G.

**On Osmotic Pressure in Solution of Metals.** A. Krupkowski. (*Bull. Acad. Polonaise Sci.*, 1957, **5**, (5), 313–322). Mathematical. A close relationship to activities is shown and the value of osmotic pressure can be calculated.

**Intergranular Corrosion Resistance of Low-Carbon Austenitic Chromium-Manganese-Nickel Steels.** W. O. Binder, J. Thompson and C. R. Bishop. (*Proc. A.S.T.M.*, 1956, **56**, 903–922). Susceptibility develops after heating to 425–815° C, and the effect of lowering C content was examined. Permissible carbon limits decrease as the sum of the Mn and Ni increases above 14%. Steels containing ~0·05%C and 14%Mn + Ni were resistant to intergranular attack after 1 h at 650° C, those with 0·02–0·025%C and with Mn + Ni not over 14% were resistant after 24 h at 650° C. Increasing Mn + Ni to 18% reduces carbon limits to 0·035 and 0·02% for these two treatments respectively.

**Stainless Steels for Corrosion Resistance.** L. R. Honnaker. (*Chem. Eng. Prog.*, 1958, **54**, Jan., 79–82). Causes of pitting, crevice and intergranular corrosion, stress-corrosion cracking and related phenomena where actual corrosion is slight are given and means for avoiding them are discussed.

**Intercrystalline Corrosion and the Attack at Grain Boundaries.** F. Erdmann-Jesnitzer. (*Werks. Korr.*, 1958, **9**, Jan., 7–16). An investigation on a non-ferrous system showed dependence upon degree of disorientation and explanations in terms of lattice energy are given.

**New Aspects of the Oxidation of Metals and Alloys at High Temperatures.** J. Bénard. (*Corros. et Anticorros.*, 1957, **5**, May, 138–145). Studies at high magnifications are made of nucleation and the effects of crystal orientation in feebly oxidizing atmospheres. The growth of the crystalline oxide layer is then followed. Particularly striking electron microscope studies of Fe-Cr alloy are shown displaying striations for which an explanation is advanced. (20 references).

**Plastic Flow of Iron Oxides and the Oxidation of Iron.** J. D. Mackenzie and C. E. Birchenall. (*Corrosion*, 1957, **13**, Dec., 783–785). Iron specimens completely oxidised to wüstite at high temperatures in pure oxygen formed a cavity equal in dimensions to the original specimen. Further increase in temperature reduced the size of the cavity. Controlled oxidation in hydrogen-water vapour did not produce a cavity. It is concluded that the inward movement of the wüstite formed is prevented or hindered when magnetite and haematite are present by the plastic properties of these oxides. An experimental determination of the plasticity of the three oxides at 800–1000° C is described. Creep was not observed in haematite or magnetite.

**Cavity Formation in Iron Oxide.** D. W. Juenker, R. A. Meussner, and C. E. Birchenall. (*Corrosion*, 1958, **14**, Jan., 39–46). A study has been made of the deep oxidation of iron at 700° to 1000° C in a pure oxygen atmosphere. Large cavities were always found in specimens whose oxygen content had been brought to that of wüstite. The scale thickness and other evidence indicates that wüstite is plastic while one or both of the higher oxides is relatively rigid. Evidence is presented that iron is transported to the scale with little or no body diffusion path. An analogous expression to the parabolic rate law for the scaling of plane specimens is developed for cylindrical ones.—J. F. S.

**Polarization in the Corrosion of Ice-Breakers.** J. H. Greenblatt. (*Corrosion*, 1957, **13**, Dec., 817–820). Measurements are reported of cathodic and anodic polarization characteristics of steel in sea water. The effects of millscale, of pickling and sand-blasting, of phosphating and of rust are compared. At low temperatures in oxygenated sea water there is considerable anodic polarization. The corrosion occurring at low temperatures is related to cathodic depolarization. The test results are discussed in terms of the observed behaviour of hulls of vessels operating in ice.—J. F. S.

**Transmission Tower Corrosion. Cathodic Protection Practice in U.S.A.** R. W. Ryder. (*Elect. Times*, 1958, **133**, Feb. 27, 325–327).

**New Theory Explains Stress-Corrosion Cracking.** E. A. Gulbransen. (*Mat. Design Eng.*, 1958, **47**, Jan., 150). Platelets of $Cr_2O_3$ have been detected on the surfaces of stressed stainless steel in atmospheres containing traces of chloride ions. These platelets tend to crack the metal.

**Growth of Oxide Whiskers on Metals at High Temperature.** R. Takagi. (*J. Phys. Soc. Japan*, 1957, **12**, Nov., 1212–1218). Electron microscope studies of $\alpha$-$Fe_2O_3$ whiskers grown on pure iron in $O_2$ at 400–850° C are discussed.

**Kinetic Studies on the Fundamental Wet Corrosion Process (Part I).** M. Takahashi. (*Bull. Faculty Eng., Yokohama Nat. Univ.*, 1955, **4**, 95–121). The anodic reaction is diffusion controlled and the cathodic reaction is activation-controlled $H_2$ evolution. Exact equations for corrosion potential and rate are obtained. Dissolution of Zn and Cd amalgams were observed in buffered solutions at pH 1–6 and this was used to confirm the theory. **Part II.** (1956, **5**, 103–120). The study is extended to aerated solutions and a polarographic study of oxygen potential on Hg is reported confirming a two-stage process with $H_2O_2$ as intermediate. A kinetic treatment of the corrosion process is then given.

**Corrosion as Affected by a Zone of Metal Emerging from the Corrosive.** P. Hersch. (*Nature*, 1957, **180**, Dec. 21, 1407–1408). The mechanism of water-line corrosion in which the three-phase boundary facilitates oxygen access is discussed. Four zones are distinguished and the potential conditions in each are examined and rates of corrosion determined.

**The Use of $^{35}S$ on Corrosion Research of Metal.** G. Shinoda, T. Tomura and S. Umeda. (*Osaka Univ., Fac. Eng. Techm. Rep.*, 1957, **7**, Mar., 117–120). Steels including stainless steels and other alloys were studied in crude oils containing radio-sulphur. The results corresponded to oil-refinery experience.

**High Temperature Hydrogen Sulphide Corrosion in Commercial Sovaformer Units.** E. B. Backensto, R. D. Drew and J. N. Vlachos. (*Corros. Techn.*, 1958, **5**, Jan., 13–16, 21). Corrosion of steels and monel in a fixed bed Pt-catalyst reforming plant is studied. Tests on 25 steels are reported, and aluminized specimens showed good resistance.

**Anodic Phenomena at an Iron Electrode.** W. H. Wade and N. Hackerman. (*Trans. Farad. Soc.*, 1957, **53**, Dec., 1636–1647). Surface condition of passivated iron was studied in acid and alkaline 0·1M $Na_2SO_4$ solutions at 5° C by two methods. The oxygen potential curves were obtained and explanations are advanced.

**Accelerated Corrosion Testing of Chromium-Plated Articles: Sulphur Dioxide Test.** J. Edwards. (*Electropl. Met. Fin.*, 1958, **11**, Jan., 17–22). A moist $SO_2$ test is described in which a controlled air-$SO_2$ mixture is blown into a test cabinet of Perspex. Correlation with outdoor exposure is good, and tests in six laboratories were consistent. Tests up to 96 h were carried out and 24 h is found to be satisfactory. Concentrations, temperatures and humidities as well as specimen shape and location are not critical.

**Two New Accelerated Corrosion Tests. An Assessment.** (*Electropl. Met. Fin.*, 1958, **11**, Jan., 15–16). The acetic acid spray and sulphur dioxide tests, recently reported, are assessed. Both are satisfactory for some materials, the former for plated Zn-base die-castings and the latter for Ni-Cr coatings on steel, but not for Ni alone.

**The Testing and Examination of Electrodeposits. 3. Salt Spray Testing.** R. Quarendon. (*Prod. Fin.*, 1957, **10**, Aug., 62–71). Control of conditions—temperature, oxygen supply, movement of corrosive agent, volume used and the size and shape and cleaning of specimens is discussed. Immersion tests, impingement, salt-spray tests proper, their limitations, the apparatus used, and the A.R.E. intermittent, and Corrodkote tests are described. (36 references). **4. Atmospheric Tests.** (Sept., 79–89). Marine, industrial, urban and rural atmospheres are classified and test panels and their arrangement, accelerated tests, criteria of performance, loss of weight tests, visual inspection and the use of scoring charts are briefly surveyed. (20 references).

**Stress Corrosion in Austenitic Steel by Nitrates.** O. Lissner. (*Eng. Digest*, 1957, **18**, Dec., 571–574; from *ASEA Journal*, 1957, **30**, (5), 85–91). The fracture of the end bell of a turbo-generator in service is described. The cause was traced to the presence of nitrates and a careful illustrated description of the crack systems found is given. Tests in 36% $Ca(NO_3)_2$, 3% $NH_4NO_3$ solution are reported, the ordinary chloride media did not produce the type of crack encountered. Precautions are suggested in design, by heat-treatment, and by the use of special stainless austenitic steels.

**Use of Stainless Steel to Combat Corrosion in the Chemical Industry.** C. P. Dillon. (*Corrosion*, 1957, **13**, Sept., 124, 126, 128, 130, 132, 134, 136–138; Oct., 138, 140, 142, 144, 146). The mechanism of corrosion resistance and errors of design or maintenance which promote corrosion are outlined. The choice of types for various conditions is considered, with an account of screening tests and their limitations, and notes on welded specimens. Behaviour in acids and in caustic is considered. Characteristic defects and their avoidance, stress-corrosion cracking in particular, are discussed and examples are shown, also hot-shortness. Fabrication is briefly reviewed and finally corrosion testing is outlined. (26 references and bibliography).

**Corrosion Control.** H. H. Uhlig. (*IVA*, 1957, **28**, (8), 351–354). [In English]. A review of cathodic, coating and passivating methods, including the use of $NaTcO_4$ is given, and a summary of the work of the M.I.T. corrosion laboratory. This concerns passivity, special studies for the electronics industry, the effects of the normal trace elements in steel (S, P, N), and stress-corrosion.

**The Prevention of Corrosion in Steam and Condensate Systems.** T. B. Fielden. (*Steam Eng.*, 1958, **27**, Jan., 123–125). Water treatments are summarised with special reference to $CO_2$ removal and the use of filming amine inhibitors is described.

**New Means for Protecting Buried Iron from Corrosion.** T. Markovic. (*Werks. Korr.*, 1957, **8**, Oct., 596–602). After a theoretical survey of the mechanism of soil corrosion, with particular reference to the water and oxygen contents of the soil, the author makes suggestions for increasing the effectiveness of the usual methods of protection. These include fixing a heavily galvanized pipe to the buried pipe to be protected, artificial aeration of the soil and the use of chemical inhibitors.—J. C. H.

**Electrochemistry of the Inhibition of the Corrosion of Iron by Red Lead.** J. D'Ans, W. Breckheimer and H. J. Schuster. (*Werks' Korr.*, 1957, **8**, Nov., 677–688). The results of an extensive physicochemical investigation of the inhibitive properties of red lead on iron are reported. Red lead acts as a cathodic depolarizer and is reduced by the bivalent iron formed at the anodes by corrosion to bivalent lead compounds, which form a protective layer on the basis metal. The earlier observation of G. Dechaux that corrosion currents can reduce red lead to metallic lead is also confirmed.—J. C. H.

**Corrosion Protection during Shipment to the Tropics.** H. Determann. (*Werks. Korr.*, 1957, **8**, Nov., 689–694). The climatic conditions to which cargoes are subjected in the holds of merchant ships are by no means the same as those prevailing in the open at the various places en route. A practical study of the subject has been made on two ships plying between Hamburg and South Africa and South America, respectively. The main causes of corrosion are marked changes in temperature and high atmospheric humidity, although bacteria, which thrive on foodstuffs such as bananas, may also play a part. Grease or wax coatings are usually an adequate protection and vapour-phase inhibitors have given good results for steel. Silica gel is also an effective anticorrosive agent, if provided in adequate quantities.—J. C. H.

**Corrosion of Steel Coated with Films from Petroleum Bitumens in Sea Water.** E. I. Gurovich and A. S. Sosnina. (*Izvest. Akad. Nauk, Otdel. Tekn.*, 1957, (4), 172–173). [In Russian]. Experimental results from the testing of bitumens, obtained in the process of desasphaltization of petroleum residues, as corrosion-protective coatings are described. Characteristics of the bitumens and the method of testing are given.—V. G.

**Water Dependent Sweet Oil Well Corrosion Laboratory Studies.** N.A.C.E. Technical Unit Committee T-IC and Task Group T-IC-2. (*Corrosion*, 1957, **13**, Nov., 747–749). Calculated values of bottomhole pH are related to tubing life in gas lift, flowing and pumping sweet oil wells. Low pH is connected with short tubing life. High iron contents and high water production are also related to short tubing life.—J. F. S.

**Theoretical Aspects of Corrosion in Low Water Producing Sweet Oil Wells.** N.A.C.E. Tech. Unit Committee T-IC. (*Corrosion*, 1958, **14**, Jan., 33–35). The principal corrosive agents in low water producing sweet oil wells are hydrolytic products of inorganic salts. When deposited on the metal either as a thin layer or a consolidated scale, hydrolysis also leads to electrolytic cells between scale and metal. A mechanism for scale deposition is discussed. Conventional methods of detecting corrosion are useless in these conditions. An analytical method of detecting corrosion is suggested.—J. F. S.

**Status of Downhole Corrosion in the East Texas Field.** N.A.C.E. Technical Unit Committee T-IC and Task Group T-IC-5. (*Corrosion*, 1957, **13**, Nov., 743–746). A report. Answers are presented to a questionnaire by oil well operators in East Texas on their use of inhibitors to prevent downhole corrosion.

**Factors Other than Mineral Content which Influence the Corrosiveness of Cooling Water.** E. H. Hurst. (*Corrosion*, 1957, **13**, Nov., 696–700). Besides mineral content the following can affect the corrosiveness of cooling waters: microbiological activity, silt and debris, suspended solids, dissimilar metals and hydrocarbon pollutions. Laboratory tests show that slime adhering to the steel increases its corrosion rate in water containing corrosion inhibitors.—J. F. S.

**Effect of Dissolved Oxygen on Corrosion and on Cathodic Protection Requirements.** G. A. Marsh and E. Schaschl. (*Corrosion*, 1957, **13**, Nov., 695). Laboratory studies are proceeding on the relationship between corrosion rate of steel, dissolved oxygen concentration, agitation, electrode potential and current density required for cathodic protection. Preliminary results suggest that corrosion of steel in neutral solutions ceases when dissolved oxygen falls to 1 p.p.m. and is not affected by agitation below 2 p.p.m. Current density requirements for protection are less in acidic than in neutral solutions. Differential aeration is an important cause of corrosion for buried structures near the water table.—J. F. S.

**Review of Carbon Steel Corrosion Data in High-Temperature, High-Purity Water in Dynamic Systems.** D. E. Tackett, P. E. Brown and R. T. Esper. (*U.S. Atomic Energy Commission, Tech. Inf. Service*, 1955, Oct. 14, *WAPD-LSR(C)*-134, pp. 203). A large series of tests showed the following factors to be without significant effect on corrosion. Variation of pH between 10·5 and 11·5 and between 7 and 9·5, differences in the materials tested in the range of carbon steels, differences in surface finish, variations in $H_2$ concentration at pH 10·5–11·5, at least with low $O_2$ concentration, variations in resistivity in the range $10^4$–$10^6$ ohm-cm., variations in velocity of water across the surface in the range 15–35 ft/sec, variations in temperature in the range 500–600° F above saturation pressures, thermal cycling between 200° F and 600° F at 1 cycle/day, whether the testing apparatus is of carbon or stainless steels, whether alkalinity is obtained with LiOH or $NH_3$ (within the range pH 10·5–11·5), differences in specimen size and shape and, type and operation of the demineralizer within the range considered. The significant factor is increase of pH from 7–9·5 to 10·5–11·5. Pretreatment techniques were tried but showed little improvement apart from a high-alkalinity treatment with LiOH. Other factors were, $H_2$ concentration, specimen handling techniques during shut-downs and mixing of new with corroded specimens.

**Galvanic Corrosion of Aluminium-Steel and Aluminium-Lead Couples.** M. J. Pryor (*Corrosion*, 1958, **14**, Jan., 1). Galvanic current and corrosion rate for an aluminium-steel couple in a chloride solution are least in the middle pH range. The rate of diffusion of oxygen to the cathode is the controlling factor. Work on the corrosion of Al in solutions containing lead compounds indicate that only if lead is deposited is corrosion aggravated. Lead soaps can inhibit the corrosion of Al if chloride and sulphate are absent.—J. F. S.

**On the Classification of the Resistance of Steels to Corrosion Under Tension in Salt Solutions Saturated with Hydrogen Sulphide.** E. Herzog. (*Compt. Rend.*, 1957, **245**, Dec. 16, 2280–2282). A killed steel normalized at 920° C, a mild steel containing Ti normalized at 980°, a medium-hard steel containing Mn-Mo normalized at 850° and a mild steel containing Cr-Mo-Al-V, quenched and tempered were examined under standardized conditions. The results show the need to simulate service conditions in laboratory testing.

**Corrosion of Ti-Fe Alloys in Hydrogen Sulphide Atmospheres at High Temperature.** K. Hirayama, N. Gamo and T. Takei. (*Reports Scientific Research Institute, Tokyo*, 1957, **33**, July, 228–233). [In Japanese].

**The Corrosion of Iron and Steel in the Salt-Crust Treatment of Mine Roads and its Suppression by Inhibiting Agents.** A. L. Godbert and M. C. White. (*Ministry of Power Safety in Mines Research Establishment, Research Report* No. 143, 1957, Oct., pp. 24). Exposure tests over long periods are reported for cast iron at various humidities. Protection was afforded by sodium chromate, nitrite, silicates and phosphate and by $ZnCl_2$.

**Dissolution of Metals, Particularly Iron and Mild Steel, in Acid.** T. Hurlen. (*Tek. Uke.*, 1958, **105**, Jan. 30, 95–101). Electrochemical corrosion covers a wide field, and to limit this the author has concentrated on the type which develops $H_2$ and on iron and mild steel as the metals affected. The basic theoretical theme which he follows may, however, be assumed to apply far beyond the particular examples which are here used to illustrate it.

**Corrosion in Mines.** M. Blazon. (*Zastita Mat.*, 1955, **3**, Mar., 93–98). The author discusses in very general terms the effect of corrosion on installations and machinery in mines, and methods of protection against corrosion and erosion.—M. deo. T.

**Corrosion Phenomena Provoked by Sulphuric Acid Solutions of Chromic Acid.** J. B. Vericad Raga. (*Anal. Real. Soc. Espan. Fis. Quim.*, 1957, **53(B)**, Dec., 751–756). [In Spanish]. The corrosive action of several chromic acid solutions, without or with sulphuric and/or nitric acid additions, upon lead, iron, brass and copper is reported. It is concluded that the corrosion phenomena produced in lead sheets of chromium-plating tanks are caused by the joint action of sulphuric and nitric acid and that the $Cr^{+++}$ion has an inhibitory action upon this attack. Iron is perfectly passive in solutions containing up to 2% of sulphuric or nitric acid. A 2·7 mm thick hardened polystyrene layer on iron was found to resist a chromic acid solution, containing 16·2% sulphuric acid, at 60–65° C for about 24 hrs.—F. S.

**Corrosion by Acetic Acid.** N.A.C.E. Task Group T-5A-3. (*Corrosion*, 1957, **13**, Nov., 757–766). Data and experience on materials of construction for storage and handling of glacial and dilute acetic acid are summarized Corrosion problems and laboratory and field tests are discussed and illustrated. Aluminium alloy or austenitic stainless steel are recommended for storing refined glacial acetic acid, although higher alloys or non-metallics may be needed occasionally. Austenitic stainless steel heating coils, pumps, valves and pipes are preferred for both glacial and dilute acid and the disadvantages of aluminium and copper or copper alloys for dilute acid are discussed. The importance of minor contaminants on the corrosivity of acetic acid is made clear and corrosion control methods are discussed.—J. F. S.

**A Kinetic Study of Acid Corrosion of Cadmium.** H. Weaver, jun., and C. C. Lynch. (*Corrosion*, 1958, **14**, Jan., 13–14). The kinetics of the reaction between dilute HCl and Cd including coatings on brass, have been studied by conductance measurements. Annealing moulded specimens reduced the corrosion rate. At higher speeds more corrosion occurred. The activation energy is between one and two kilocalories per mole. The reaction was of zero order over 90% of the reaction process; the rate-controlling step is believed to be diffusion rates in the solution around the Cd.—J. F. S.

**Fuel Ash Attack on Aluminium Coated Stainless Steel.** J. E. Srawley. (*Corrosion*, 1958, **14**, Jan., 36–38). A laboratory investigation of the resistance of hot-dip Al coated Type 310 stainless steel to attack by residual oil ash constituents is described. The coated specimens were no better than the bare steel nor did heat treatment of the coated specimens improve matters. Results of a boiler test agreed with the laboratory findings.

**The Effect of NO, $HNO_2$, and $HNO_3$ on Corrosion of Stainless Steel by $H_2SO_4$.** W. P. McKinnell, jun., L. F. Lockwood, R. Speiser, F. H. Beck and M. G. Fontana. (*Corrosion*, 1958, **14**, Jan., 9–12). An 18/8 stainless steel activated by abrasion and immersed in 10% $H_2SO_4$ was passivated if nitric oxide was bubbled through the solution but not if oxygen was bubbled through instead. Abraded specimens exposed to a nitric oxide atmosphere before immersion in nitric oxide-free sulphuric acid remained active. Spot tests revealed both nitrite and nitrate ions present in sulphuric acid after bubbling nitric oxide. The addition of one part of 10% $HNO_2$ to 60 parts of 10% $H_2SO_4$ produced passivity of abraded stainless steel exposed in it but not if urea was added to remove nitrous acid. It is concluded that nitrous acid is required for passivation.—J. F. S.

**Inhibiting Effect of Hydrofluoric Acid in Fuming Nitric Acid on Liquid and Gas Phase Corrosion of Several Metals.** D. M. Mason, L. L. Taylor and J. B. Rittenhouse (*Corrosion*, 1957, **13**, Dec., 821–827). Measurements were made at 130° F of the corrosion of metals exposed to the liquid and gas phases of nitric acid containing 11 to 13% of $N_2O_4$ and 2 to 4% water with and without hydrofluoric acid added as inhibitor. The 18–8 Cr-Ni stainless steels were passivated in both phases if exposed to the inhibited acid and were fairly stable in the uninhibited acid. They broke down rapidly however if there had been previous intergranular attack on the steel. Steels containing less than 15% Cr and no Ni were only passivated if previously oxidized in moist air and in the presence of the inhibitor. The passive film was destroyed more readily as the Cr content decreased and these materials are not recommended. In certain alloys, the gas phase corrosion was increased by HF. 15 and 25% Cr steels were passivated in the presence of the inhibitor and are recommended for inhibited fuming nitric acid. Repeated temperature fluctuation between 70° and 160° F was found not to impair the inhibiting effect on gas and liquid phase corrosion of an 18–8 stainless steel (and of an aluminium alloy).—J. F. S.

**Corrosion and Metal Transport in Fused Sodium Hydroxide. Part 3—Formation of Composite Scales on Inconel.** G. P. Smith, M. E. Steidlitz and E. E. Hoffman. (*Corrosion*, 1958, **14**, Jan., 47–52). Inconel was exposed to fused sodium hydroxide at temperatures of 450° to 815° C and for times up to 400 h. The observed reaction is shown to be the selective leaching of iron and chromium from the nickel. The reaction product of oxides and oxysalts grew into the metal in a network of channels, whose geometry was much affected by the various experimental conditions and is described in detail. Rate measurements are also reported.—J. F. S.

**Corrosion Products Formed in the Reaction between Fused Sodium Hydroxide and Iron-Rich Alloys of Iron, Chromium and Nickel.** G. P. Smith and E. E. Hoffman. (*U.S. Atomic Energy Commission, Oak Ridge Nat. Lab. ORNL-2156, TID-4500*, 1957, May 14, pp. 8). Measurements on 304 and 347 stainless steels in NaOH at 815° C, and four high-purity Fe-Cr-Ni alloys were made. Each corroded layer was found to consist of a non-metallic network threaded through a metallic matrix like those found in corroded Inconel.

**Atmospheric Exposure Tests of Wire and Wire Products.** A.S.T.M. Subcommittee XV. (*Proc. A.S.T.M.*, 1956, **56**, 133–137). Inspections of Pb and Zn coated wires at various locations are reported.

**Preliminary Report on Status and Evaluation of Carbon Steel.** H. F. Beeghly. (*U.S. Atomic Energy Commission, Tech. Inf. Extension, WAPD-CP-622*, 1954, pp. 40). Corrosion tests on A212 carbon, steel are reported showing that after an initial conditioning period, it falls to a low rate, 50 mg/dm² per month is given as a basis for reactor component design. pH and other water conditions are considered including the effect of Mn. The cost of carbon steel for reactor construction would be attractive.

**Accelerated Corrosion Tests for the Performance of Plated Coatings.** W. L. Pinner. (*Plating*, 1957, **44**, July, 763–766). The acetic acid salt spray test and the Corrodkote Test using a slurry of $Cu(NO_3)_2$, $FeCl_3$ and $NH_4Cl$ solutions with kaolin are described.

**Accelerated Corrosion Testing of Chromium-Plated Articles—Sulphur Dioxide Test.** J. Edwards. (*Bull. Inst. Met. Finish.*, 1957–8, **7**, Winter, 55–78). A series of investigations on the permissible variations in $SO_2$ content, humidity and temperature is reported, showing that the necessary limits are easily maintained and that 24 h is usually long enough for testing. The corrosion pattern developed resembles that from outdoor exposure and reproducibility at different times and in different laboratories is good. Many test panels are shown.

**A Concentrator for Coordinated Corrosion Testing.** O. Henderson and L. Horvath. (*Corrosion*, 1957, **13**, Dec., 799–802). An instrument is described by means of which nineteen simultaneous voltage readings can be taken using one voltmeter. The voltages are stored as charges on a series of 4 MF. capacitors which are isolated simultaneously from their separate external test circuits and then read off one by one on the voltmeter. The concentrator has proved valuable in testing complex bonding schemes to eliminate corrosion by stray currents from traction systems.—J. F. S.

**Testing Specimens for Gas Corrosion Under Stress.** M. Ya. L'vovskii and G. E. Moskalenko. (*Zavods. Lab.*, 1957, **23**, (11), 1374–1376). [In Russian]. The authors point out that the results of prolonged strength tests in highly heat-resisting sheet materials are often vitiated by the occurrence of accelerated gas corrosion under stress at very high temperatures. They describe a method in which a marked test-piece of varying cross section is subjected to experimental conditions for 100 h and is then examined. Microstructures of Nichrome specimens are shown and the dependence of the degree of oxidation on the deformation tabulated. The method is not very accurate but simple and applicable to the highest temperatures. Estimates of creep can be made by it.—S. K.

**Rate of Oxidation of Carbon Steels at Different Temperatures on Vacuum Diffusion of Nickel and Chromium.** S. S. Pani, K. C. Som and G. P. Chatterjee. (*Trans. Indian Inst. Met.*, 1956–57, **10**, 195–199). The oxidation resistance of mild steel rods plated with Ni followed by Cr was determined in air at 500° and 600° after subjecting the specimens to a diffusion anneal at 950° C in a vacuum. Plated specimens given a 4 h anneal were found to oxidize more than those given a 2 h anneal.—B. C. W.

**The Use of An Improved Inert Coating for Masking Corrosion Test Specimens.** G. Butler and E. C. Seabrook. (*Chem. Ind.*, 1958, Feb. 8, 155–156). The use of polytrichloroethylene is described.

**A Copper Ion Displacement Test for Screening Corrosion Inhibitors.** W. B. Hughes. (*J. Petroleum Techn.*, 1958, **10**, Jan., 54–56). The test is particularly adapted to oil well casings. The material to be tested is applied to an iron surface and the amount of Cu deposited from solution is determined. The results correlate well with practical trials.

**An Evaluation of Inhibitors for Corrosion Prevention in an Engine Cooling System.** L. C. Rowe. (*Corrosion*, 1957, **13**, Nov., 750–756). The selection of inhibitors for engine cooling systems using water or glycol-water mixtures is discussed. Laboratory tests of six inhibitors indicate that satisfactory results with uncoupled steel, cast iron, copper, aluminium, brass and solder can readily be achieved if chlorides and sulphates are absent. When these are present sodium nitrite, potassium dichromate (for water) or soluble oil are preferred to sodium borate, benzoate or mercaptobenzothiazole. With the metals coupled in pairs, a mixture of soluble oil, sodium nitrite and sodium mercaptobenzothiazole was devised which gave satisfactory results in a model engine cooling system. The contribution of pH control is examined.

**Inhibiting a Cooling Water Tower System.** F. L. Whitney, jun. (*Corrosion*, 1957, **13**, Nov., 711–718). Experience of the use of inhibitors in two major recirculating tower systems demonstrates the value of coupon tests in both plant and laboratory. Contamination of the water by atmospheric pollution and in return lines can greatly increase its aggressivity. Chromate and chromate/phosphate inhibitors proved superior to sodium silicate or phosphate alone even with pH control. The absence of scale formation arising from inhibition is important.

**Some Experiences with Sodium Silicate as a Corrosion Inhibitor in Industrial Cooling Waters.** J. W. Wood, J. S. Beecher and P. S. Laurence. (*Corrosion*, 1957, **13**, Nov., 719–724). Results of low-carbon steel coupon tests in eight plants using sodium silicate as inhibitor are presented. Crystalloidal silica is found to be highly effective in stopping corrosion in a wide variety of industrial cooling waters. Even in the presence of 500 p.p.m. of chlorides and sulphates, a concentration of 50 p.p.m. silica is enough to prevent attack. High pH or Mg contents exceeding 250 p.p.m. (as $CaCO_3$) interfere. Some corrosion is necessary before protection begins.—J. F. S.

**A Thermochemical Study of Some Additives to Reduce Residual Fuel Ash Corrosion.** W. E. Young and A. E. Hershey. (*Corrosion*, 1957, **13**, Nov., 725–732). The melting point characteristics of a number of binary mixtures of $V_2O_5$ or sodium sulphate with Al, Mg, Ca and Si compounds have been studied. It is postulated that an additive which increased the melting point of the fuel ash would prevent the "catastropic" attack on refractory alloys in gas turbines. Simplified formulæ for estimating melting points of mixtures have been developed. Aluminium compounds seem the most promising, but further full scale trials under operating conditions are required. More extensive and accurate thermochemical data would be valuable in selecting additives for test.

**Controlling Corrosion of Textile Mill Air Conditioning Equipment.** J. S. Livingstone. (*Corrosion*, 1957, **13**, Nov., 147–148). A summary of a paper describing operating conditions of air conditioning equipment in textile mills. Some design defects are pointed out and remedial measures suggested. Vinyl and zinc-rich paints are recommended in the application conditions prevailing.—J. F. S.

**Current Requirement for Cathodic Protection of Oil Well Casing.** E. W. Haycock. (*Corrosion*, 1957, **13**, Nov., 767–774). Six criteria commonly used for indicating the minimum current required for complete protection in cathodic protection systems are discussed with particular reference to their application to the protection of deep oil well casings. Laboratory experiments are described involving the application of cathodic protection currents to several galvanic cells in series. It is suggested that a modification of the log current-potential curve method will give a truer indication of the minimum current requirement. The effect of incomplete protection is not believed to be serious.—J. F. S.

## MISCELLANEOUS

**The Ergonomic Aspects of the Design of Cranes.** R. G. Sell. (*J.I.S.I.*, 1958, **190**, Oct., 171–177). [This Issue].

**Ergonomic Investigations into the Design of Master Controllers.** A. Box and R. G. Sell. (*J.I.S.I.*, 1958, **190**, Oct., 178–187). [This Issue].

**The Plane-frame Method of Analysis for Lattice Girders.** R. G. Tyler. (*J.I.S.I.*, 1958, **190**, Oct., 187–196). [This Issue].

**Human Temperature Regulation and the Steel Industry.** R. F. Hellon. (*J.I.S.I.*, 1958, Oct., **190**, 197–200). [This Issue].

**Devices and Developments in Engineering Psychology.** C. R. Gibbs. (*J.I.S.I.*, 1958, **190**, Oct., 201–204). [This Issue].

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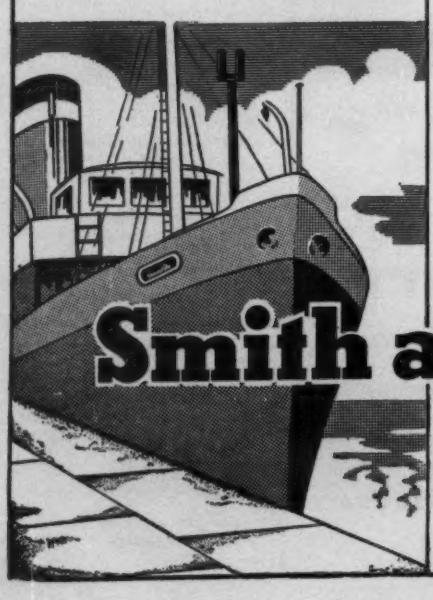

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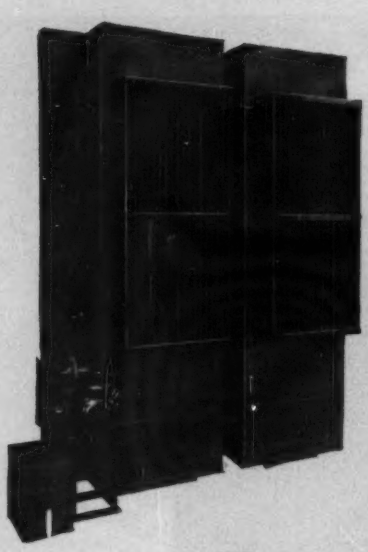

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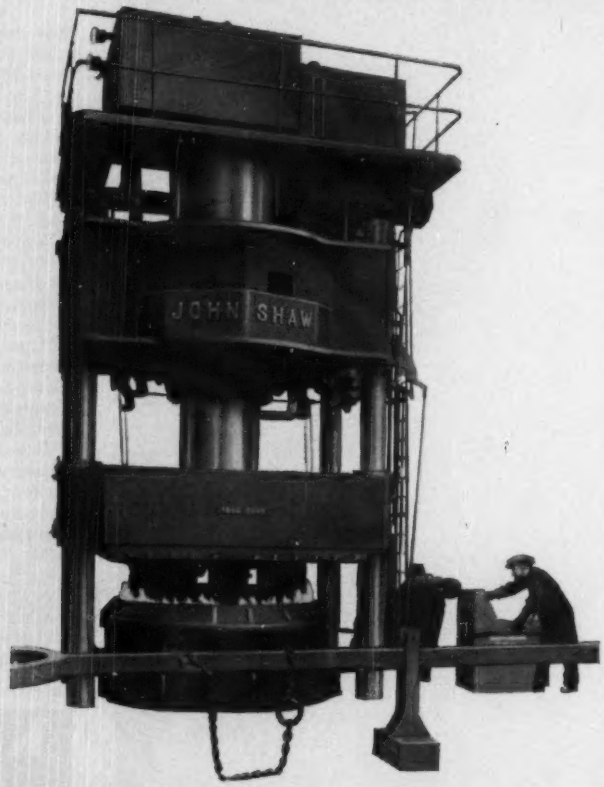


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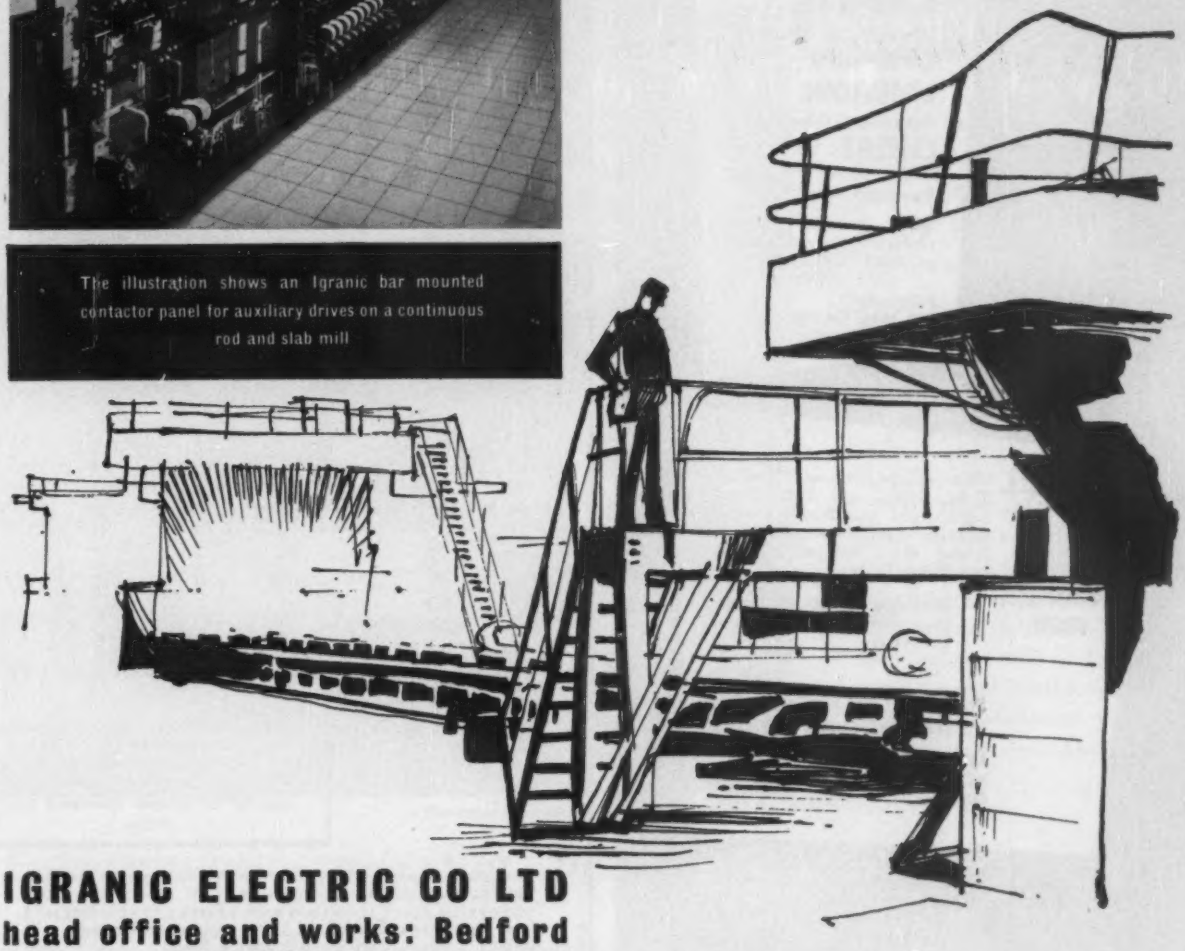

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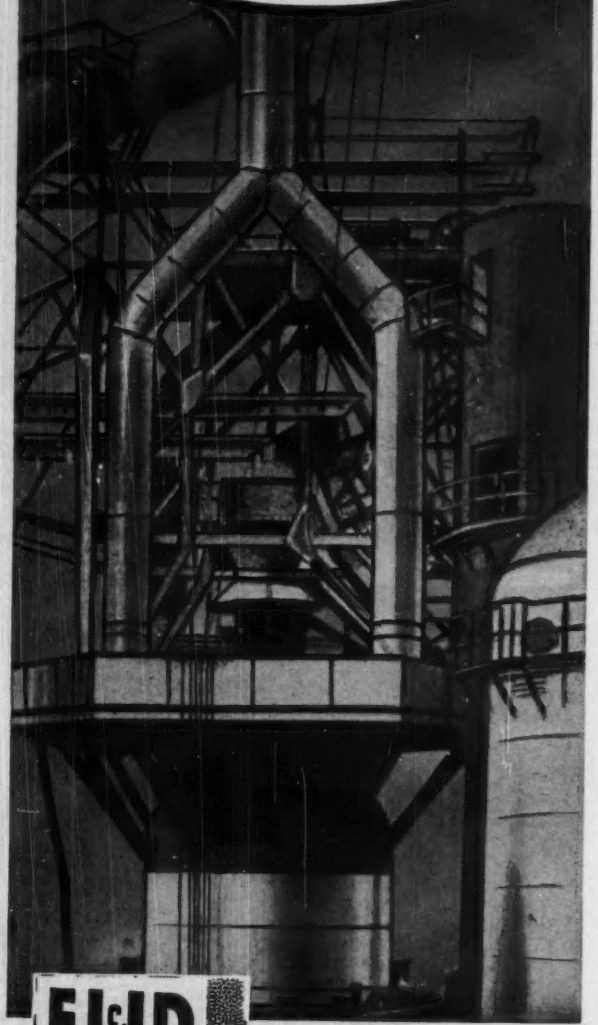

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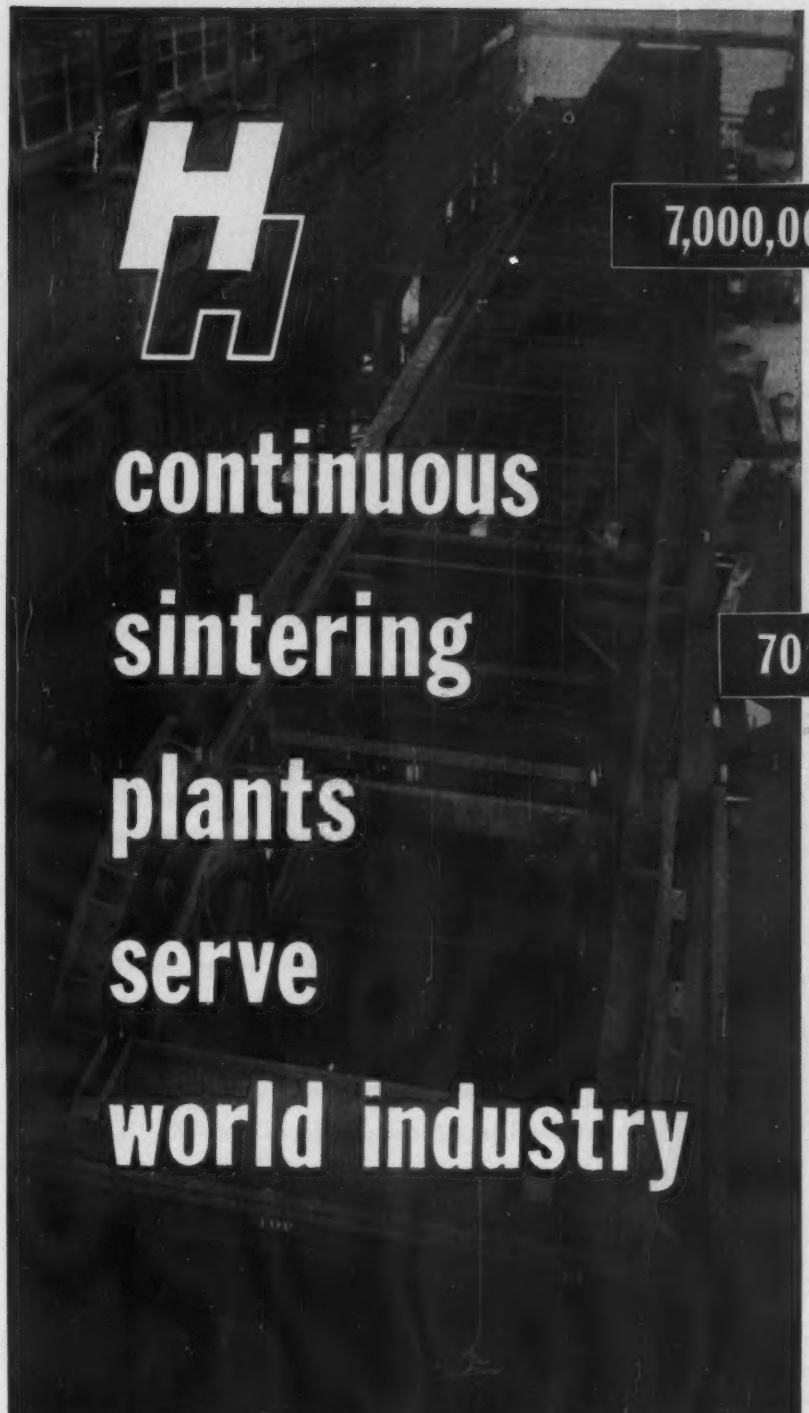


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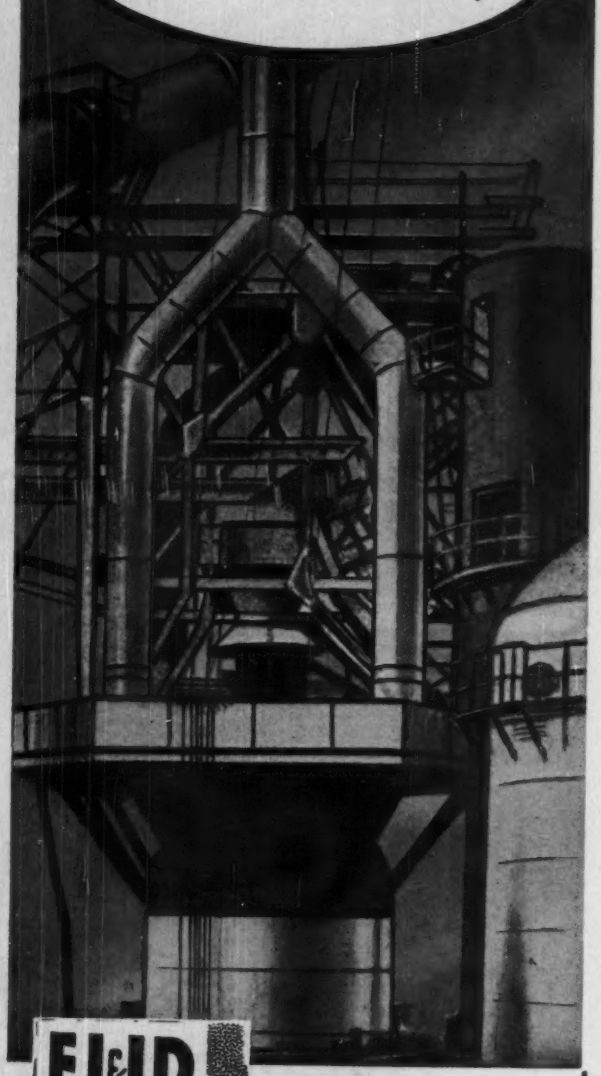

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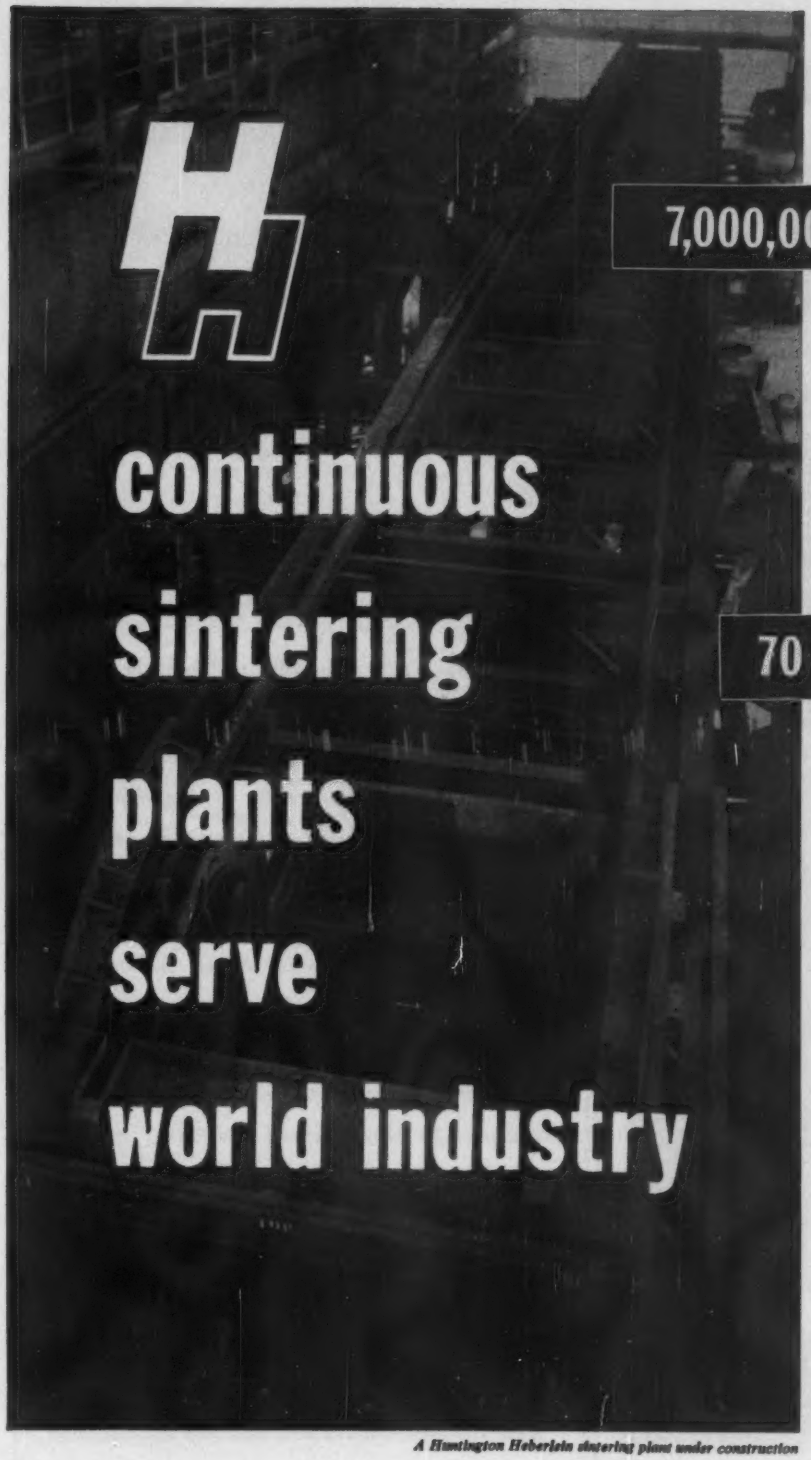

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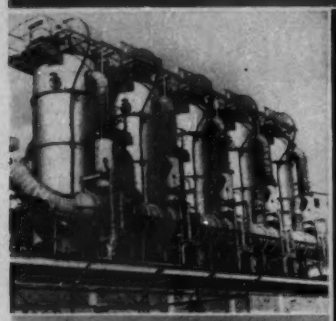
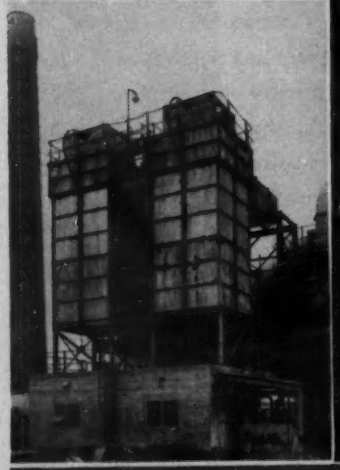


mist from sulphuric acid contact plants

pyrites dust from Turbulent Layer roasters



phosphoric acid fume

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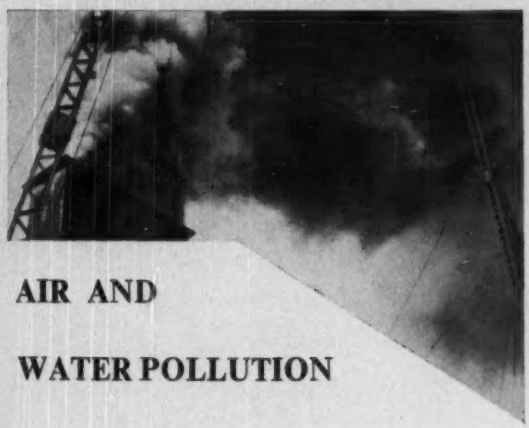

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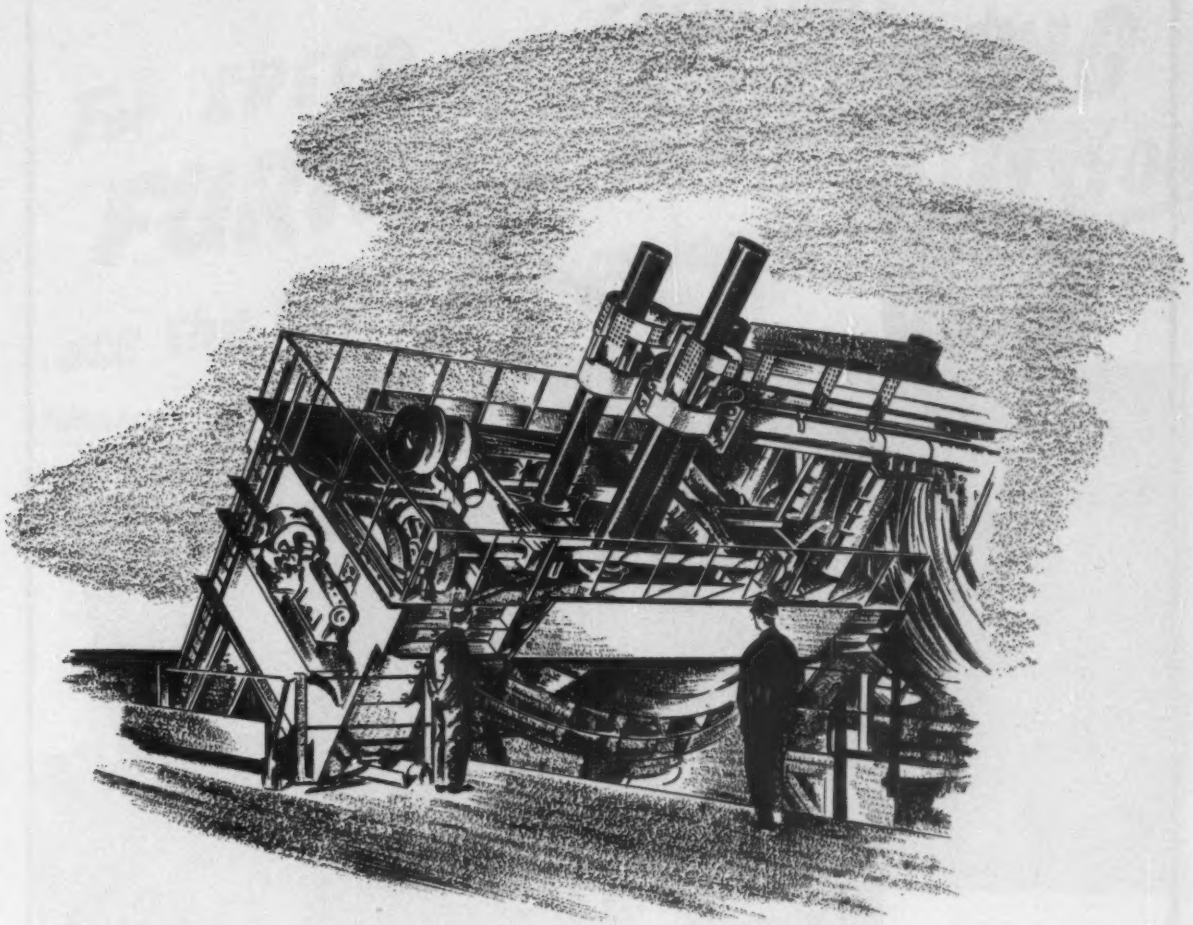
ON 25th-26th September and on 11th-12th December, 1957, in anticipation of the Clean Air Act, 1956 and the Rivers (Prevention of Pollution) Act, 1951 coming into full effect in June and August, 1958 respectively, the Iron and Steel Engineers Group of the Institute held two meetings on Air Pollution and Water Pollution in the Iron and Steel Industry.

Twenty-five papers were written especially for the meetings, by authors from Austria, France, Germany, the U.S.A., and the U.K. During the meetings some lively and informative discussions took place, in which experts in a variety of fields gave their views. The papers, reports of the discussions, and contributions received subsequently to the meetings, together with additional authors' replies, have now been published as a Special Report in one volume of 260 pp.

The report, No. 61 in the Special Report series of the Institute, is illustrated with over 200 diagrams and photographs and is bound in cloth with stiff board covers. Copies can be obtained from the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, price £4 5s. 0d. (Members £4 5s. 0d.)



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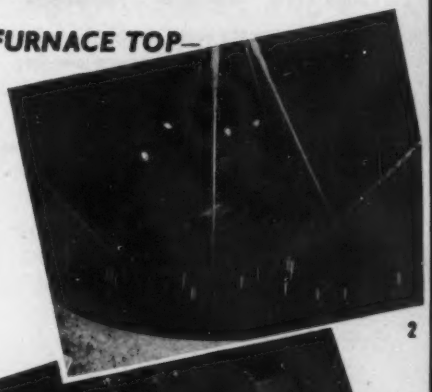

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**–TO FURNACE BOTTOM**

1

1 *'Lumpy going'—half-way down hearth.*
2 *Men removing throat armour.*
3 *Cat Traxcavator commencing digging, Cast House Floor Level.*
4 *The two 'cats' meet—final 'break through'.*

Scenes of operations at No. 1 Blast Furnace
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| | |
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| **Furnace blown out** | 23rd April 1958 |
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**TOTAL TIME** wrecking burden, lining, hearth and bear
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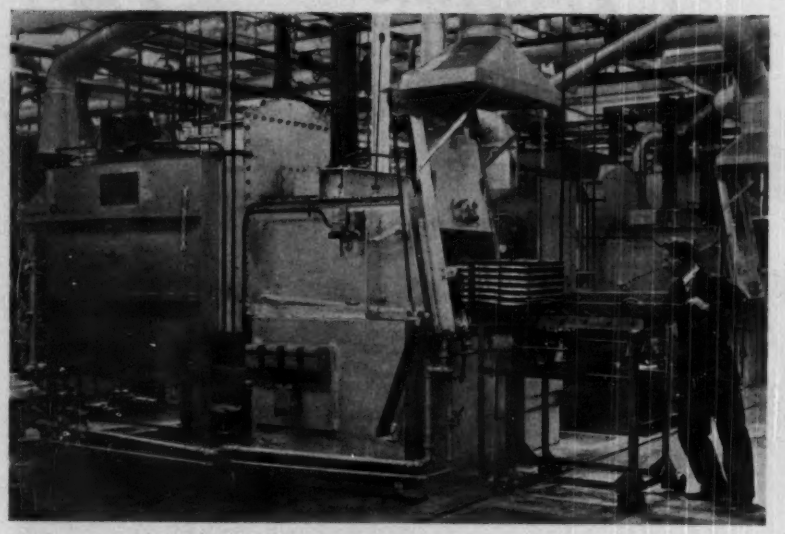

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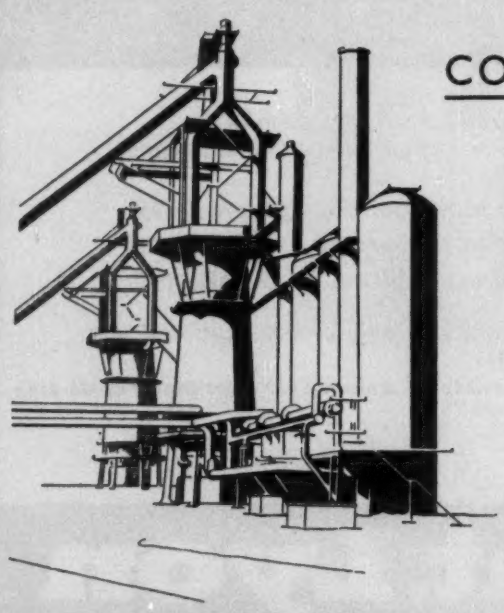

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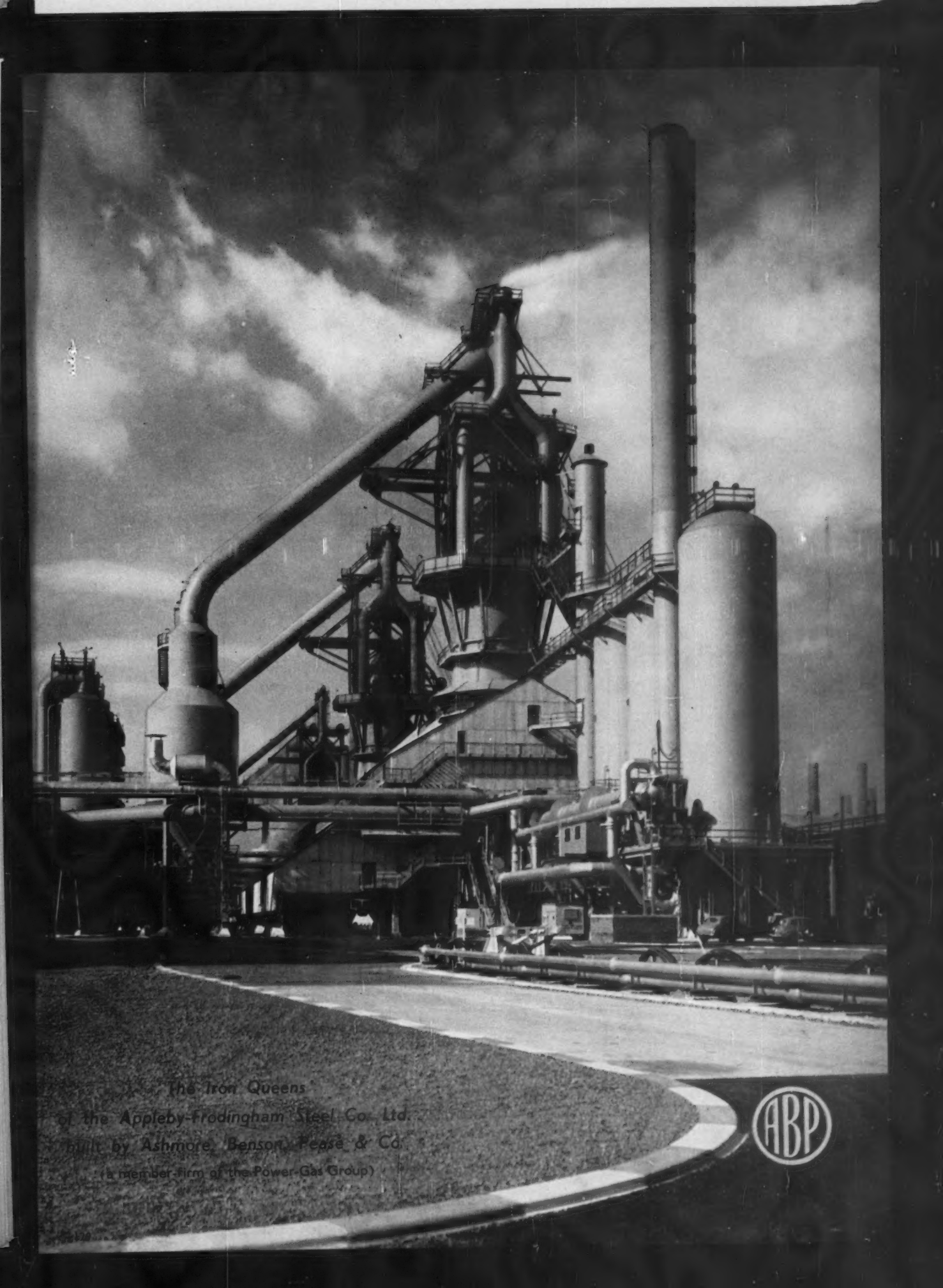
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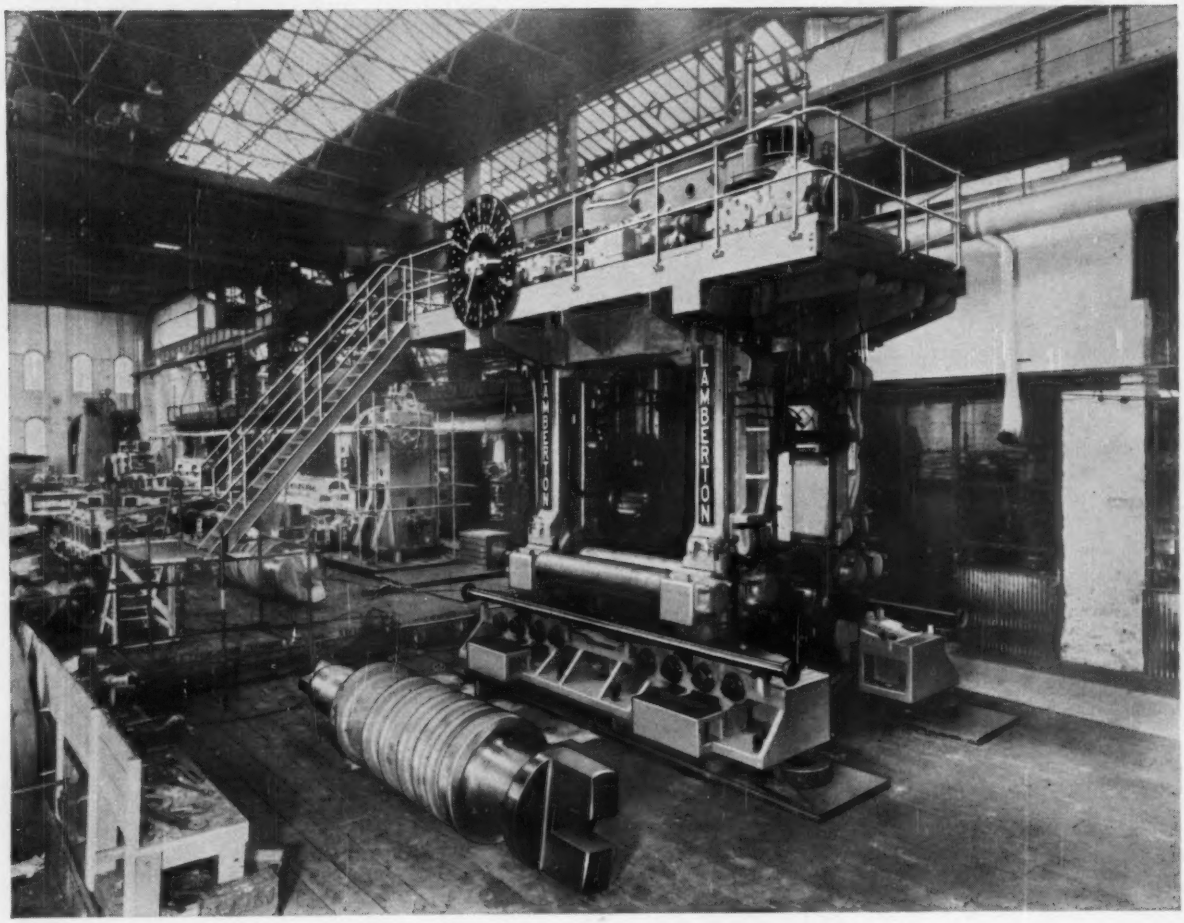


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